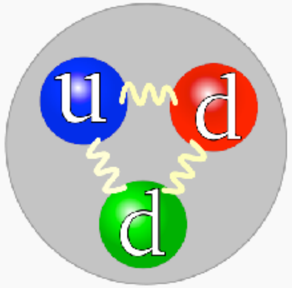
# McStas Introduction and general concepts

# Agenda

- A (very) brief introduction to McStas
- Components of neutron instruments
- How McStas works under the hood
- Components and instruments
- A demo

# McStas: Neutrons, Monte Carlo & ray-tracing

**Neutron**




The quark structure of the neutron. (The color assignment of individual quarks is not important; what is important is that all three colors are present.)

| | |
|---|---|
| **Classification** | Baryon |
| **Composition** | 1 up quark, 2 down quarks |
| **Statistics** | Fermionic |
| **Interactions** | Gravity, Weak, Strong, Electromagnetic |
| **Symbol** | $n$, $n^0$, $N^0$ |
| **Antiparticle** | Antineutron |
| **Theorized** | Ernest Rutherford[1][2] (1920) |
| **Discovered** | James Chadwick[1] (1932) |
| **Mass** | $1.674\,927\,351(74) \times 10^{-27}$ kg[3]<br>$939.565\,378(21)$ MeV/$c^2$[3]<br>$1.008\,664\,916\,00(43)$ u[3] |
| **Mean lifetime** | 881.5(15) s (free) |
| **Electric charge** | 0 e<br>0 C |
| **Electric dipole moment** | $<2.9 \times 10^{-26}$ e·cm |
| **Electric polarizability** | $1.16(15) \times 10^{-3}$ fm$^3$ |

| | |
|---|---|
| Life time: | $\tau_{1/2} = 890s$ |
| Mass: | $m = 1.675 \times 10^{-27} kg$ |
| Charge: | $Q = 0$ |
| Spin: | $s = \hbar/2$ |
| Magnetic moment: | $\mu/\mu_n = -1.913$ |

$$\boxed{E = \frac{1}{2}mv^2 = \frac{\hbar^2 k^2}{2m}, \qquad \lambda = 2\pi/k}$$

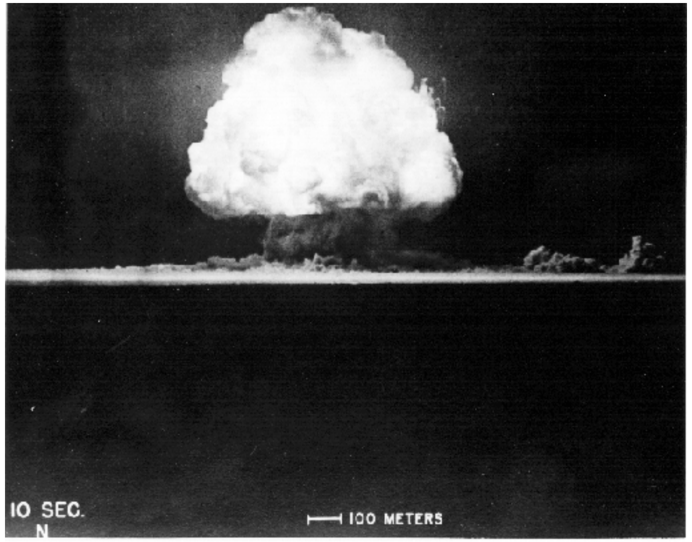
$$\boxed{E = 81.81 \cdot \lambda^{-2} = 2.07 \cdot k^2 = 5.23 \cdot v^2}$$

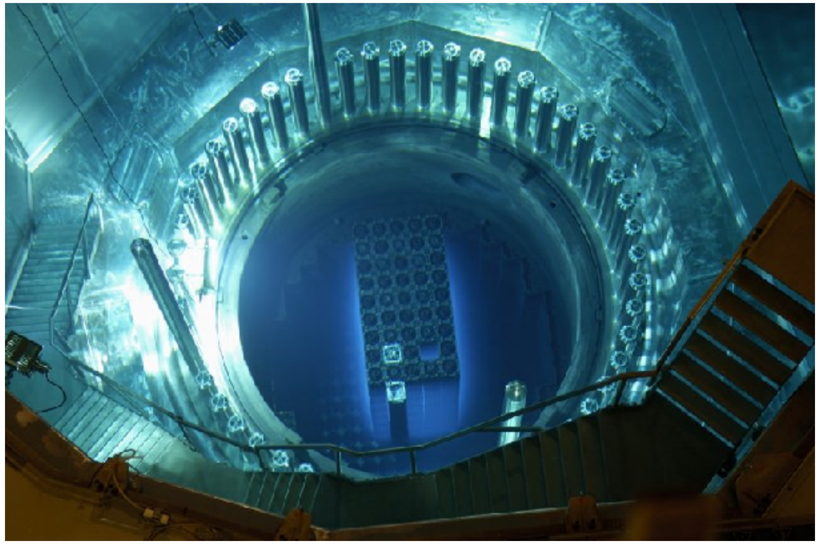
**Subatomic particle discovered by Sir James Chadwick in 1932**

| | Energy | Wavelength | n-Wavevector | Velocity | Frequency |
|---|---|---|---|---|---|
| cold neutrons: | E = 1 meV | l = 9.0446 Å | k = 0.6947 1/Å | v = 437 m/s | v = 0.2418 THz |
| | E = 5 meV | l = 4.0449 Å | k = 1.5534 1/Å | v = 978 m/s | v = 1.2090 THz |
| thermal neutrons: | E = 25 meV | l = 1.8089 Å | k = 3.4734 1/Å | v = 2187 m/s | v = 6.045 THz |
| | E = 50 meV | l = 1.2791 Å | k = 4.9122 1/Å | v = 3093 m/s | v = 12.090 THz |

# Monte Carlo techniques

- Los Alamos has since then developed and perfected many different monte carlo codes leading to what is today known as the codes MCNP5 and MCNPX
- State of the art is MCNP6 that features numerous (even exotic) particles
- MCNP was originally Monte Carlo Neutron Photon, later N-Particle
- Mainly used for high-energy particle descriptions in weapons, power reactors and routinely used for estimating dose rates and needed shielding
- Not much focus on crystalline / ordered material and coherent scattering of neutrons due to the focus on high energies





# Examples of Monte Carlo programs

***Each time physics takes place (scattering, absorption, …) random choices are made.***

*Light ray-tracing: PoV-RAY and others …*

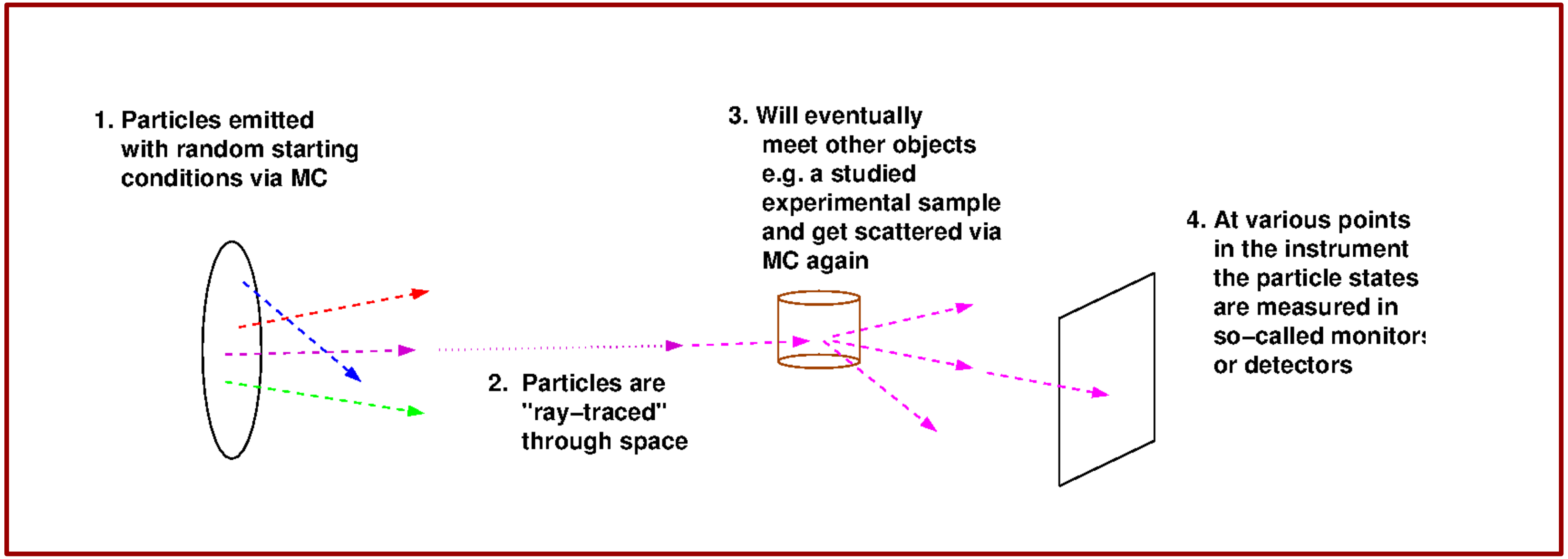
*Nuclear reactor simulations etc. (general particle transport):*
*MCNP, Tripoli, GEANT4, FLUKA*

*Neutron Monte Carlo ray-tracing propagation:*
***McStas <www.mcstas.org>**, Vitess, Restrax, NISP, IDEAS, McVine*
*Neutrons are described as **(r, v, s, t)**, and are transported along instrument models.*
*Propagation simply uses Newton rules, incl. gravitation.*

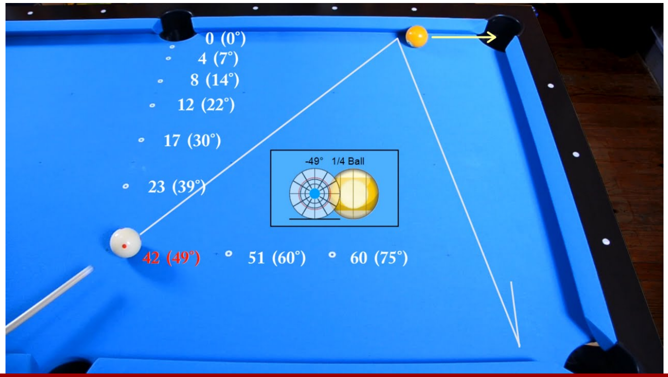
*X-ray tracing*
*Shadow, McXtrace, RAY, …*

DTU
EUROPEAN SPALLATION SOURCE

# In the big picture, McStas is this…




- Classical Newtonian mechanics, i.e.

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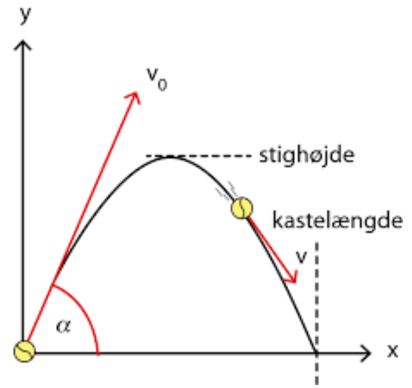


- (independent, particles though…)

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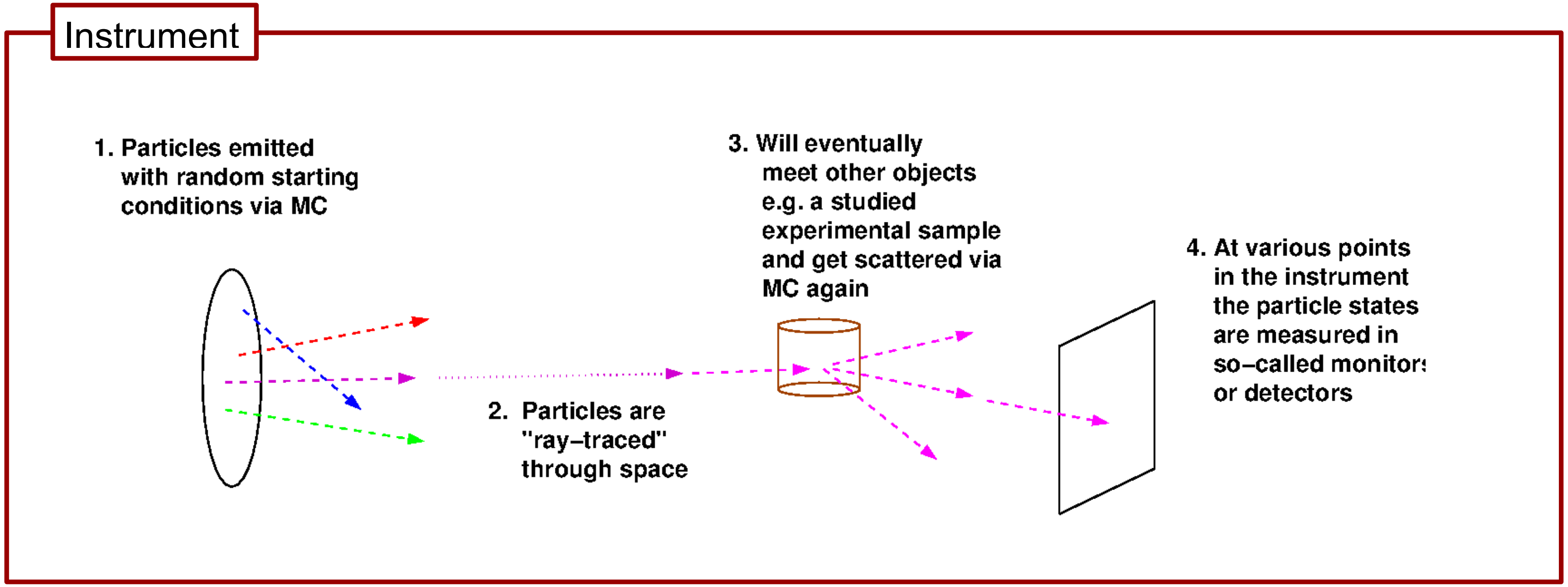
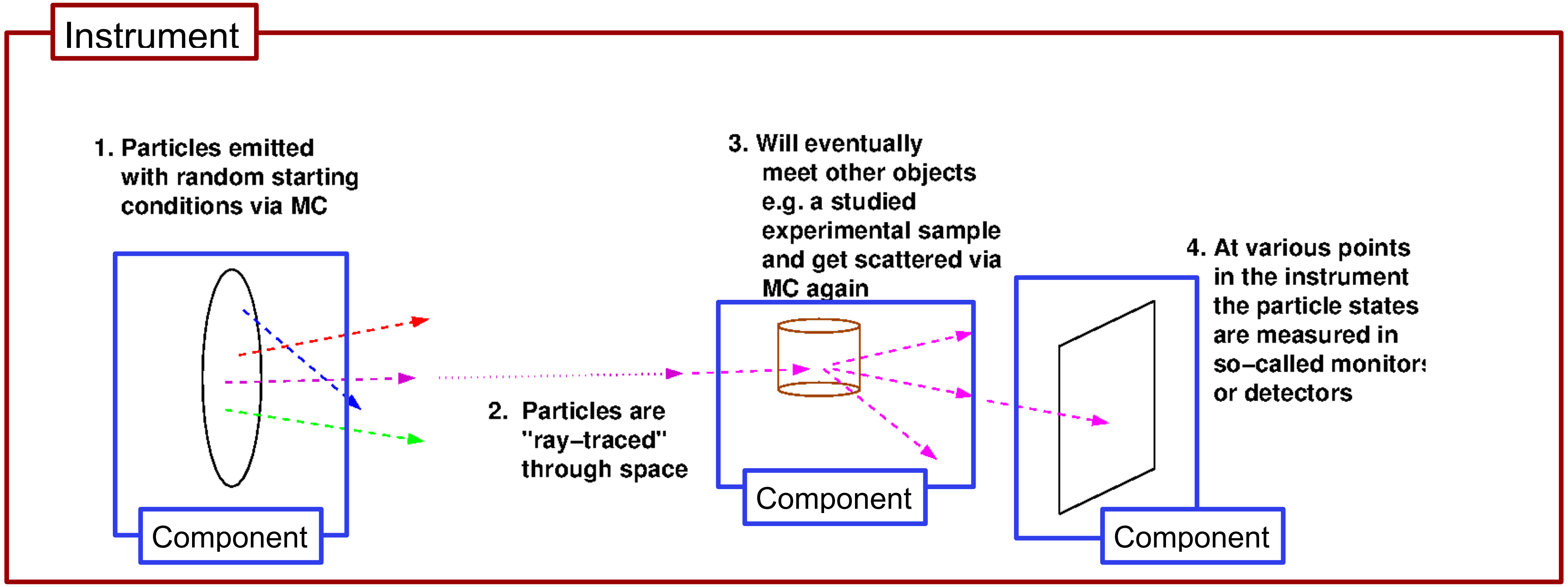



The instrument defines our "lab coordinate system"

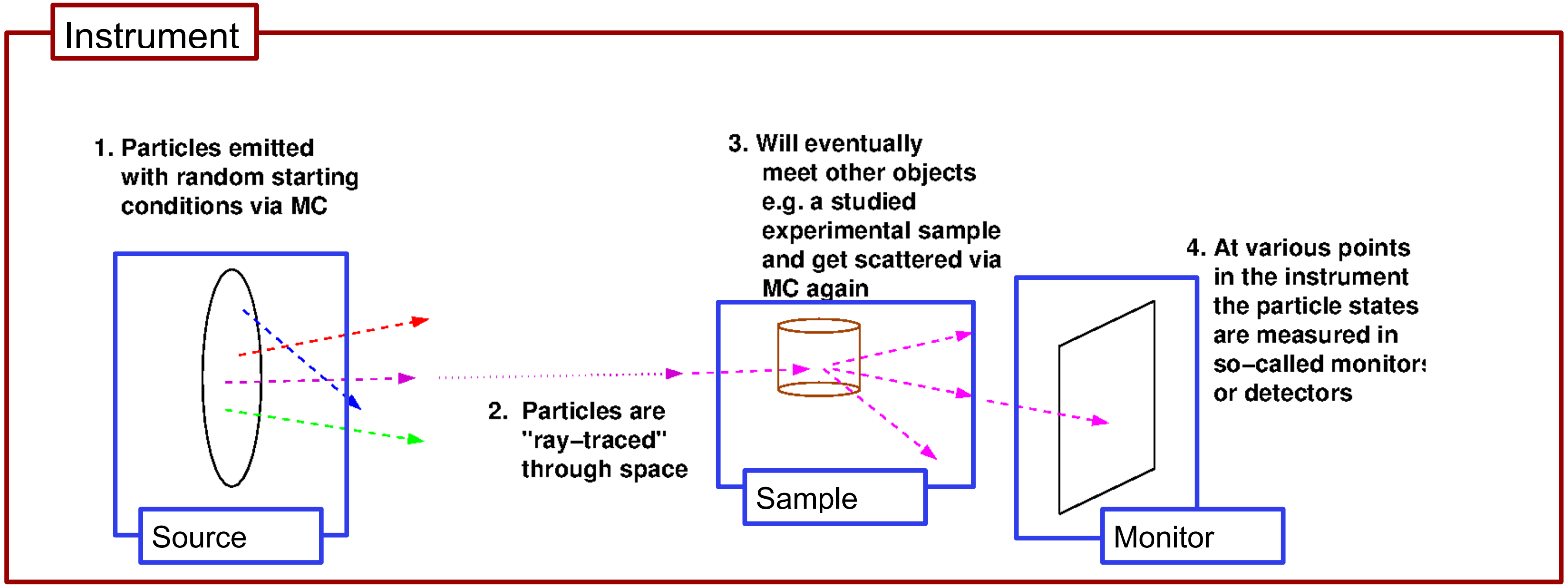
# In the big picture, McStas is this…




The instrument defines our “lab coordinate system”

The components define devices or features available in our instrument

# In the big picture, McStas is this…

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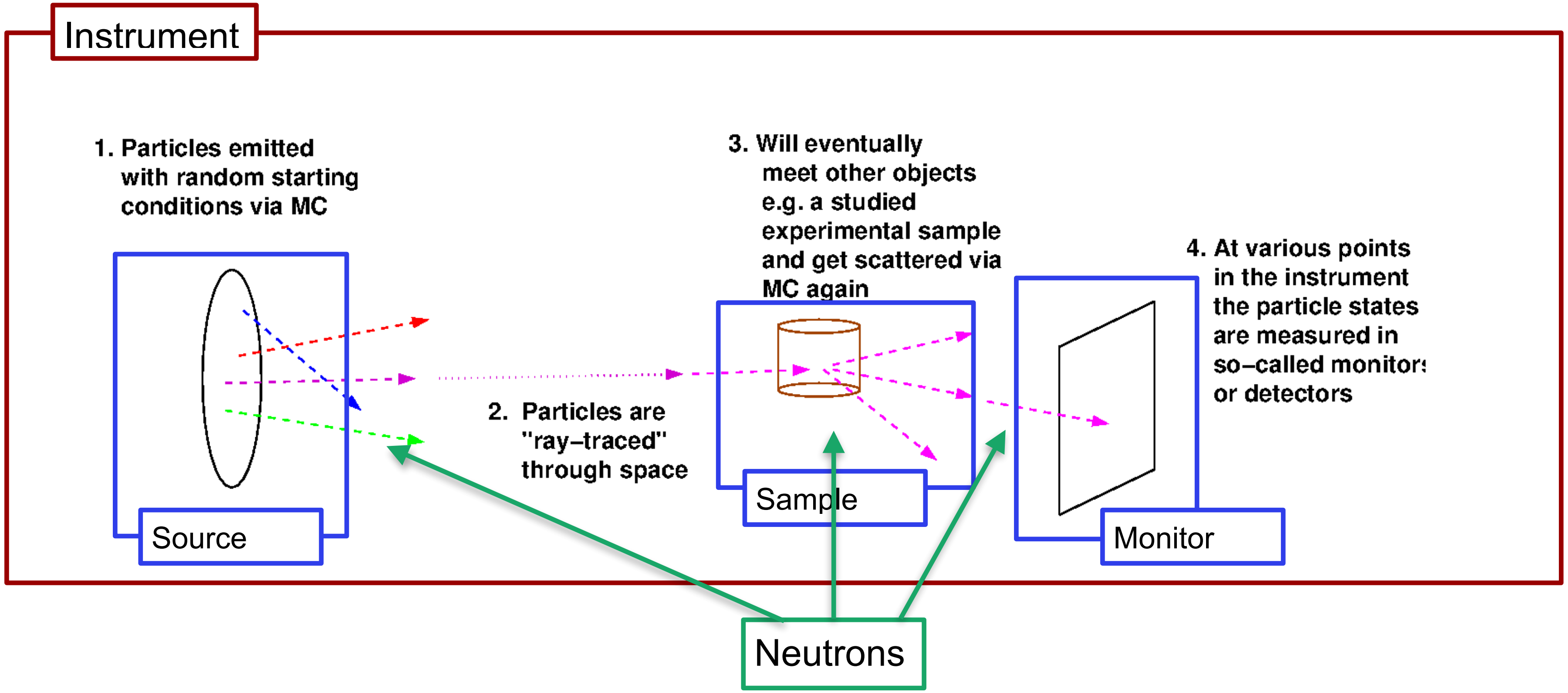
The components define devices or features available in our instrument - they have different function

# In the big picture, McStas is this…

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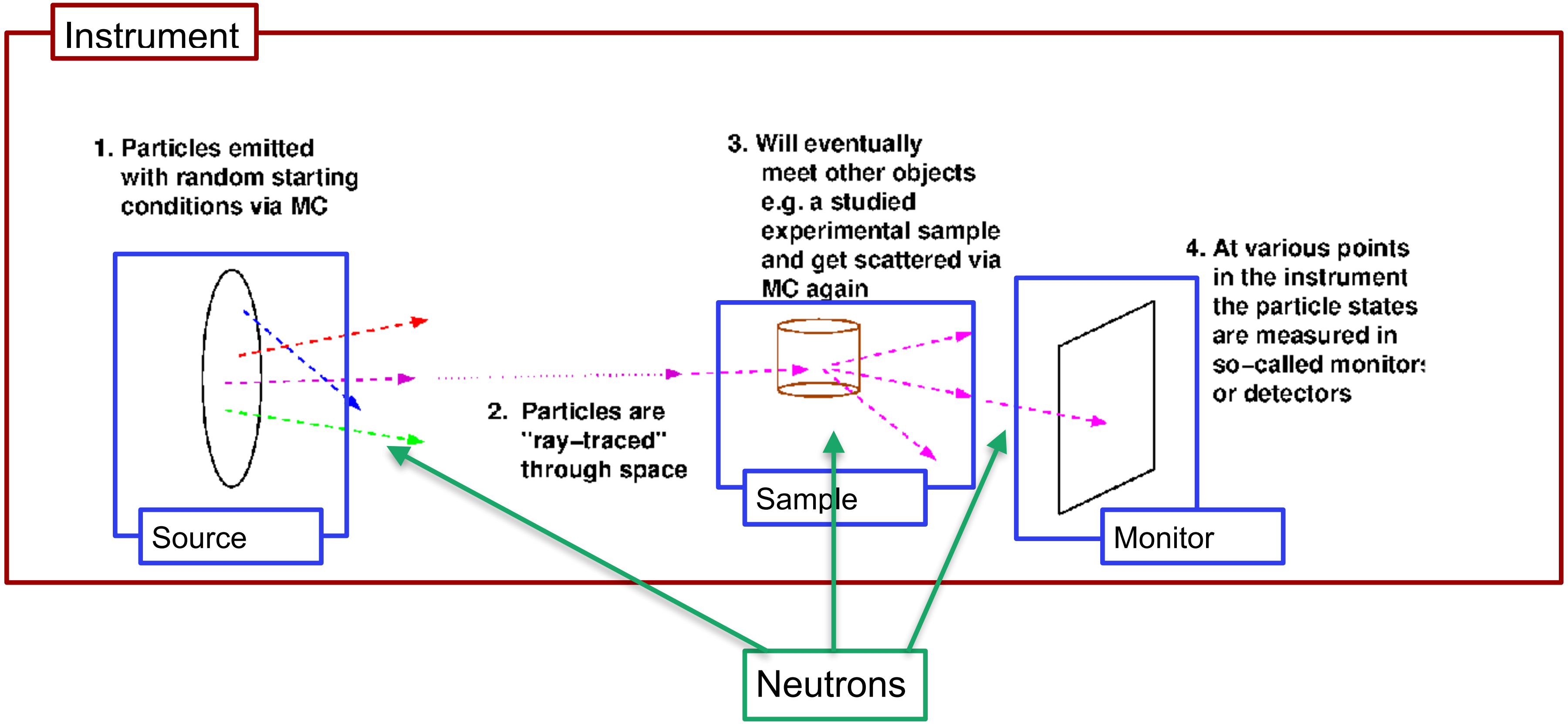
The components define devices or features available in our instrument - they have different function

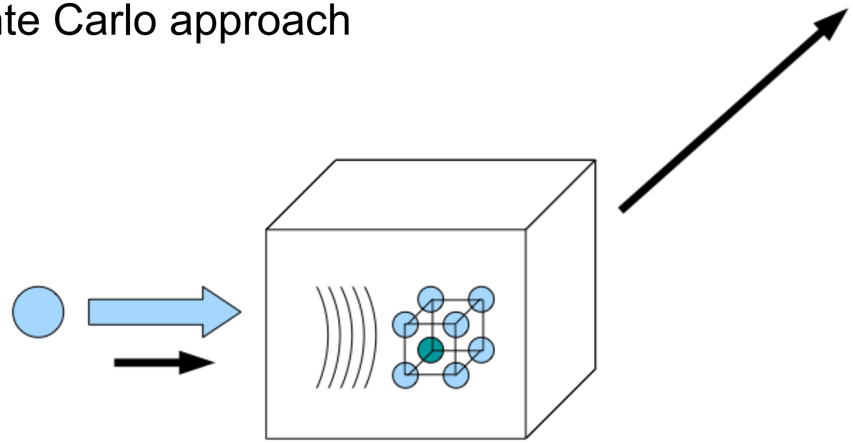
Neutron particles are passed on from one component to the next, changing state under way

# McStas is a Monte Carlo ray-tracer



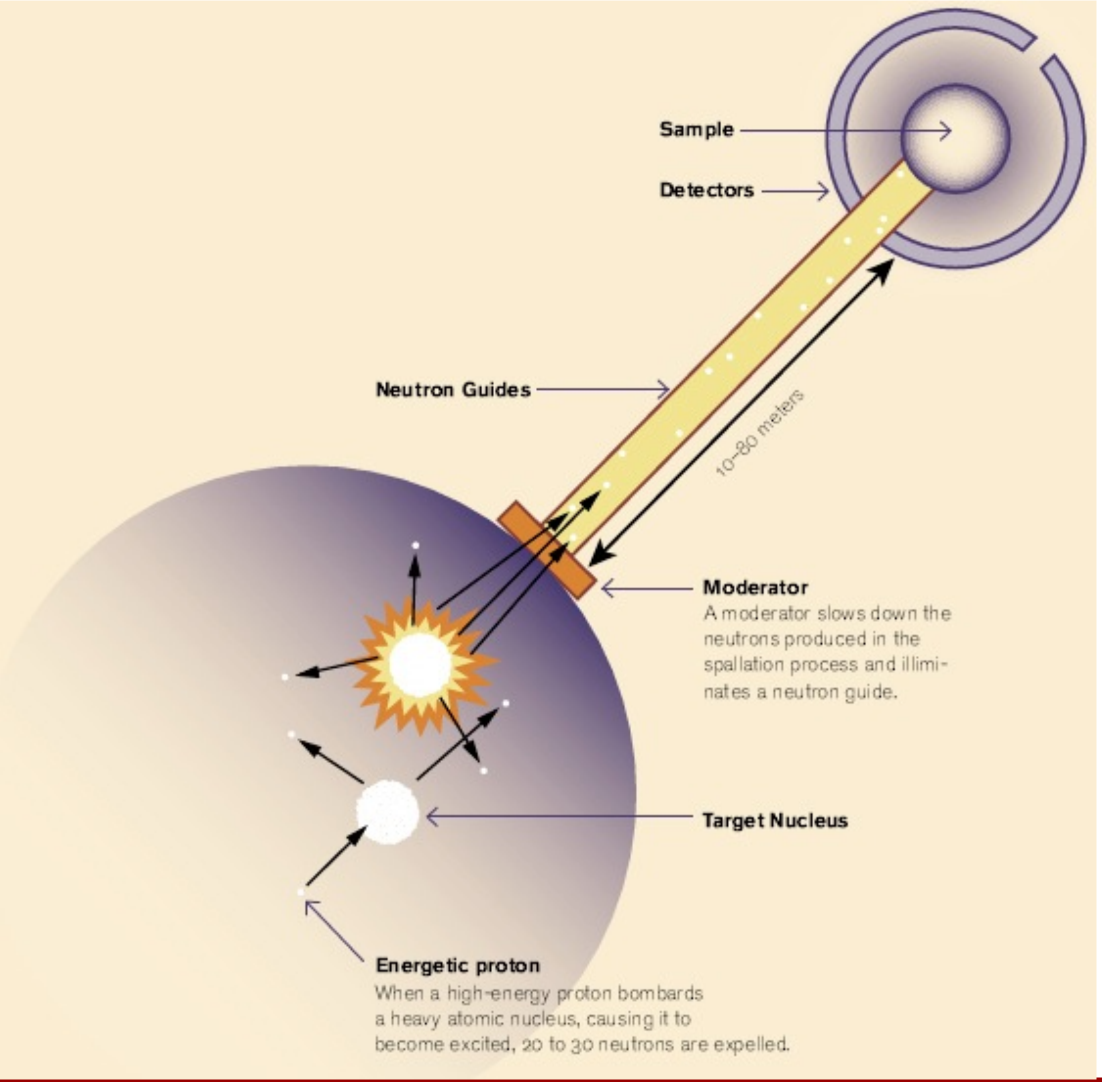
# Elements of Monte-Carlo raytracing

- Instrument Monte Carlo methods implement coherent scattering effects
- Uses deterministic propagation where this can be done
- Uses Monte Carlo sampling of “complicated” distributions and stochastic processes and multiple outcomes with known probabilities are involved
- - I.e. inside scattering matter
- Uses the particle-wave duality of the neutron to switch back and forward between deterministic ray tracing and Monte Carlo approach



- Result: A realistic and efficient transport of neutrons in the thermal and cold range

# Components of neutron instruments



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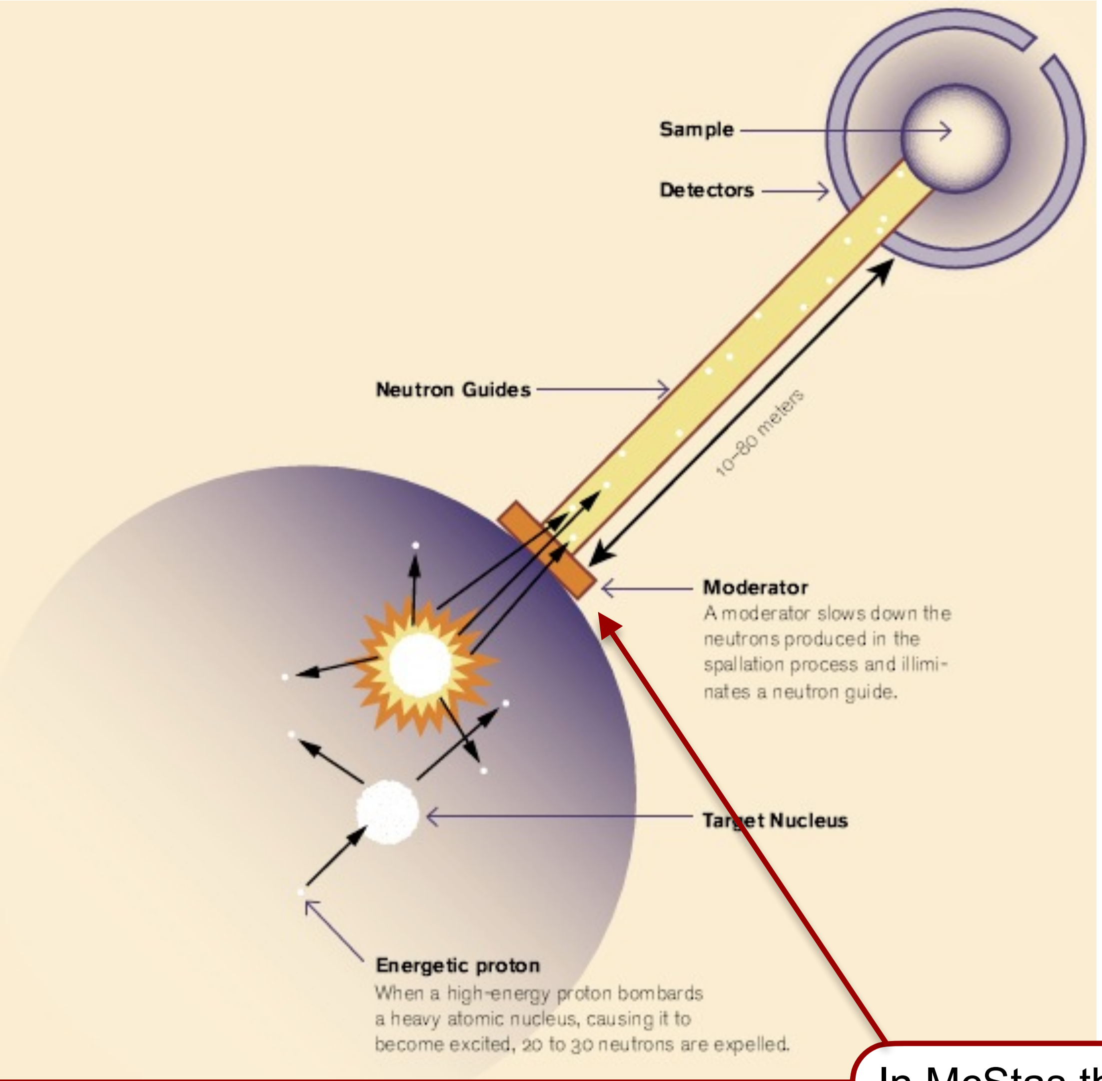
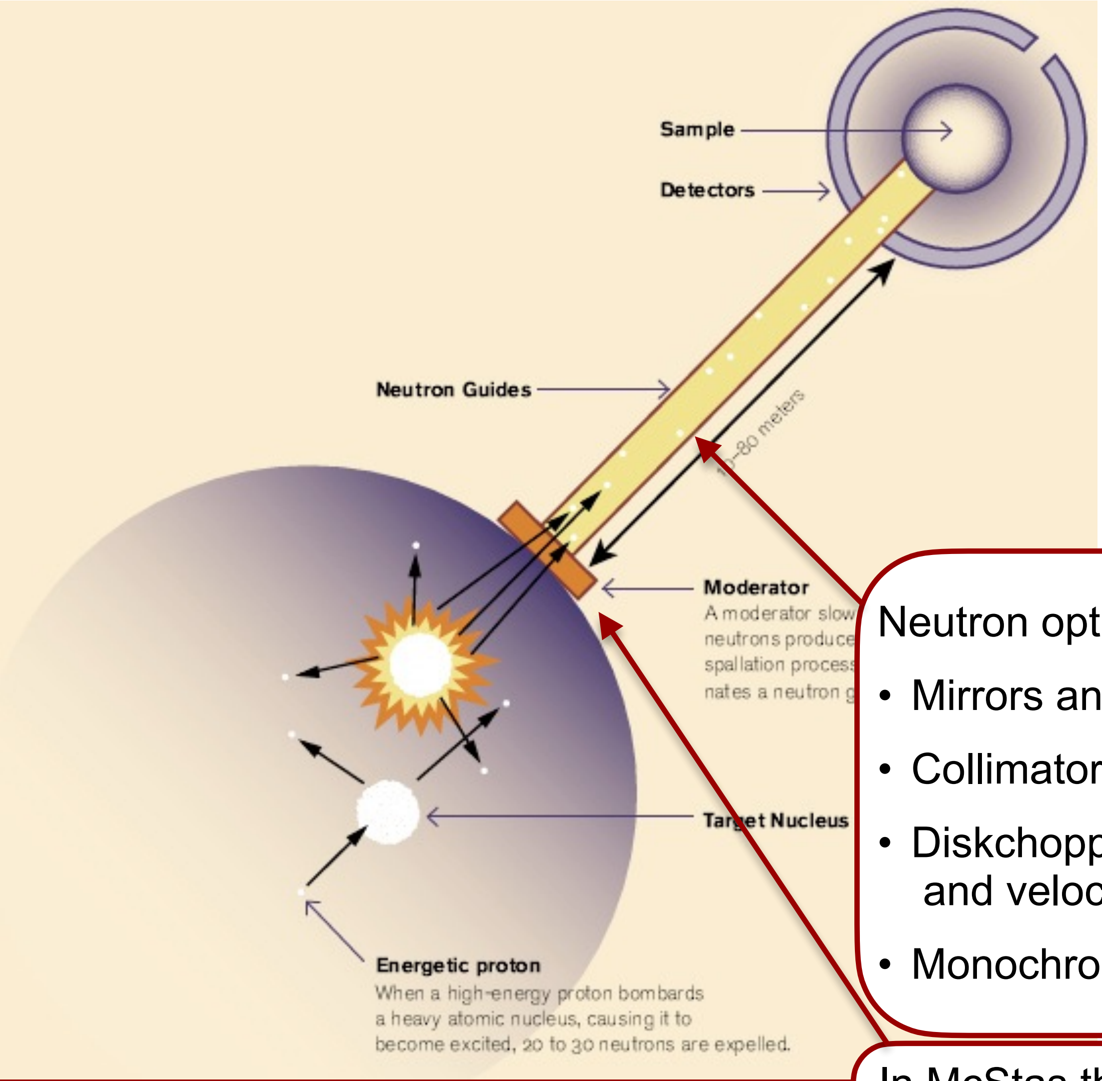


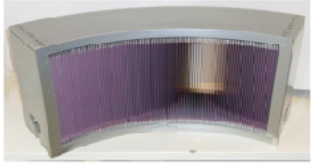

In McStas the moderator is the “source”

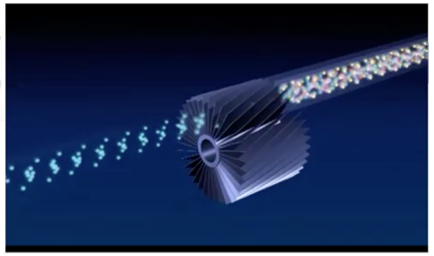
# Components of neutron instruments

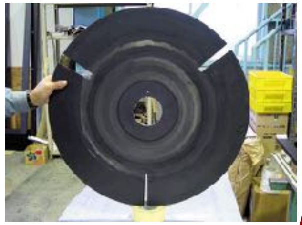



Neutron optics include things like:

- Mirrors and guides
- Collimators and slits
- Diskchoppers, Fermi choppers and velocity selectors
- Monochromators/Analysers







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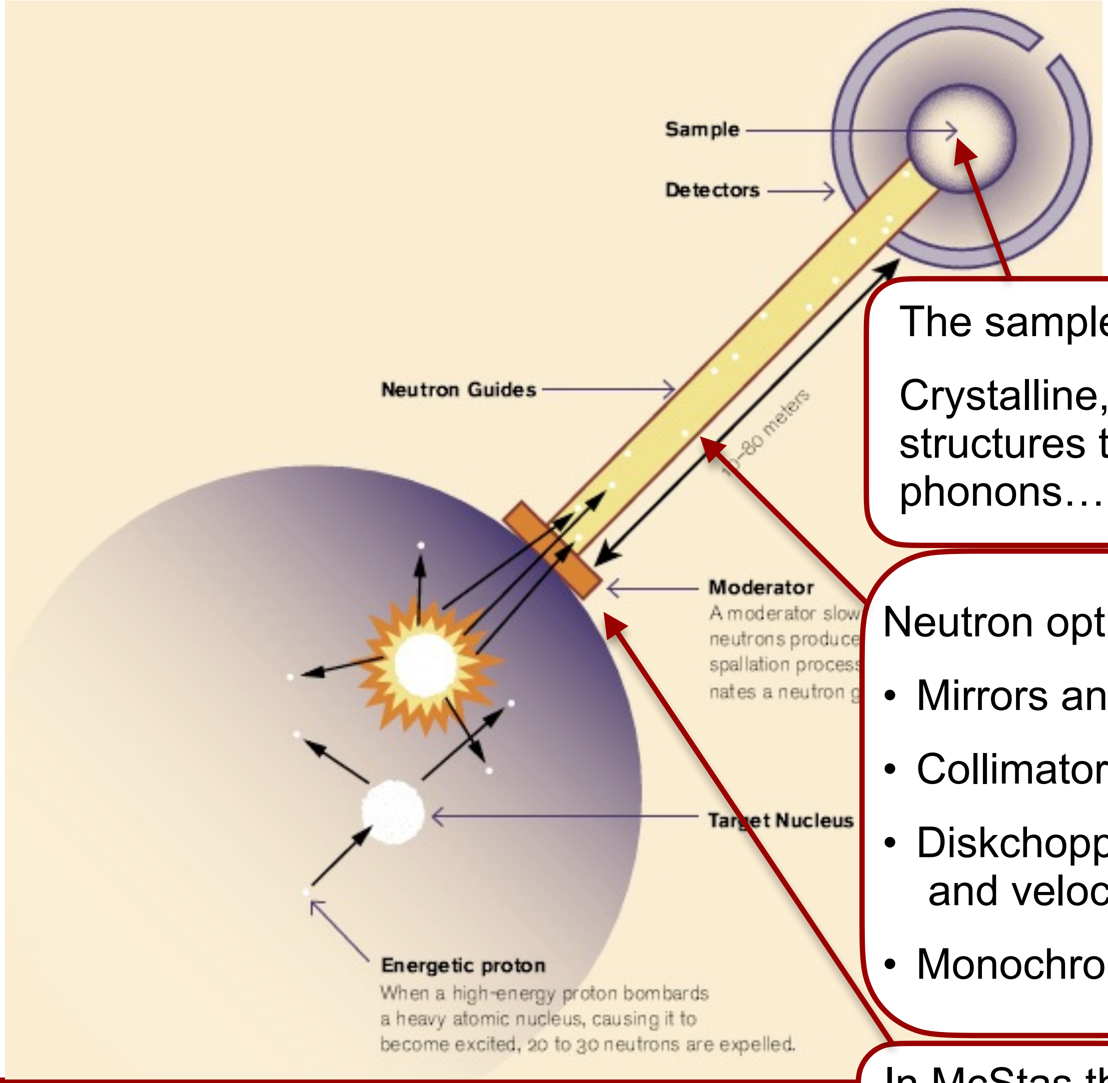
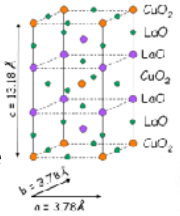
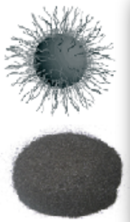



The sample:

Crystalline, powders, liquids, micelles, structures to image, inelastic features like phonons…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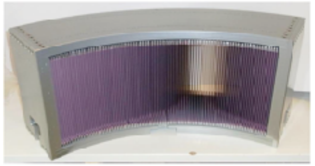

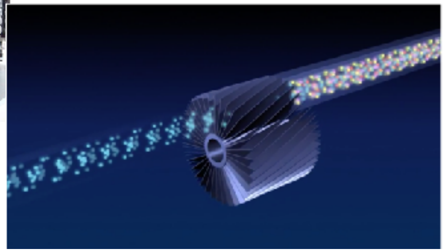
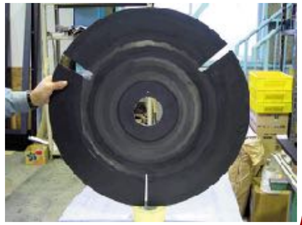

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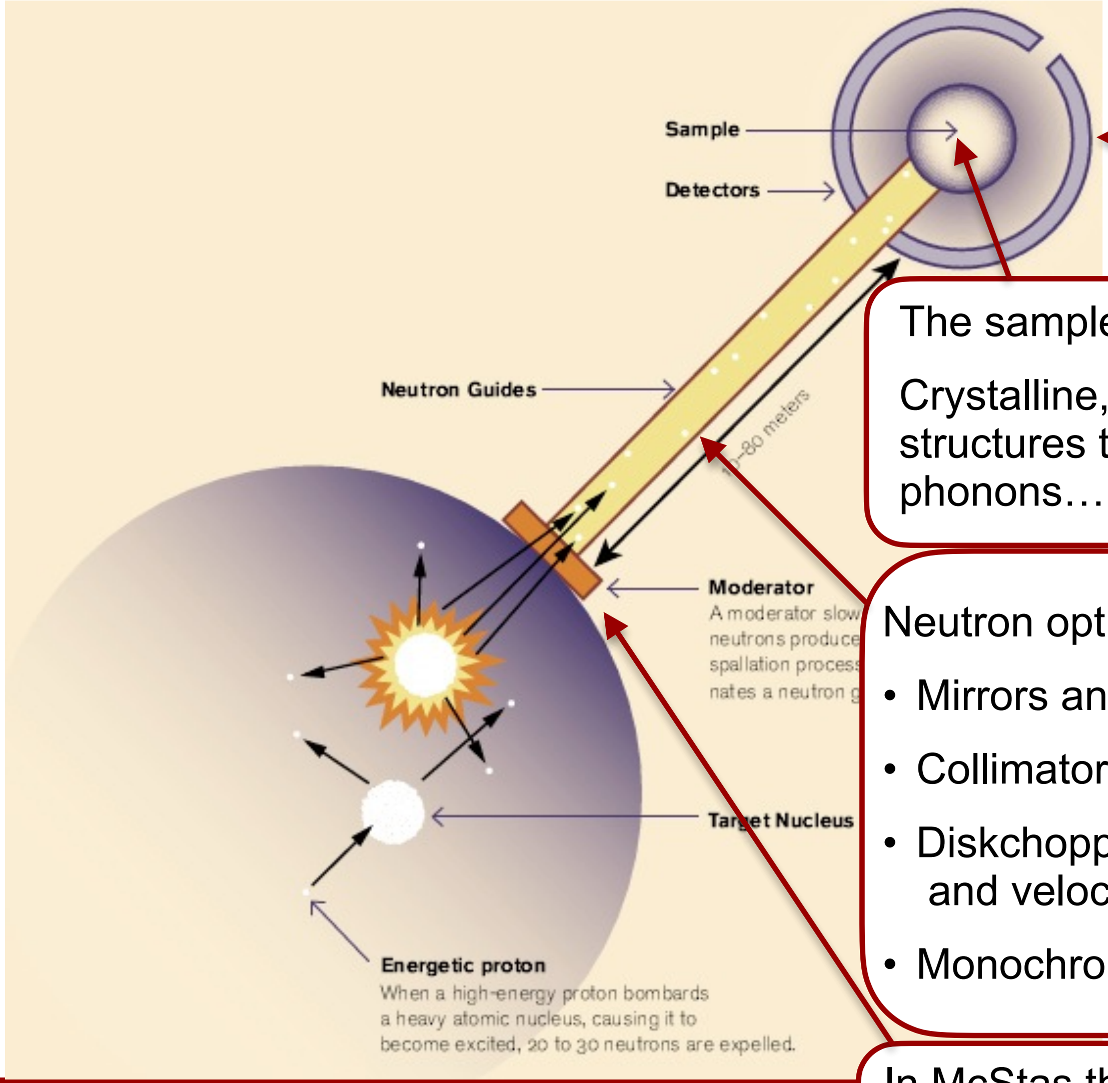
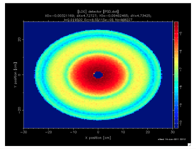
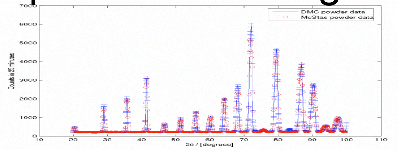



Detectors are “monitors” in McStas. Mostly they act as “perfect probes” and can be positioned thought your instrument gathering 1D/2D/ event lists…





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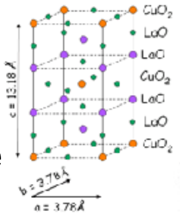


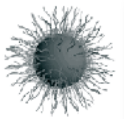

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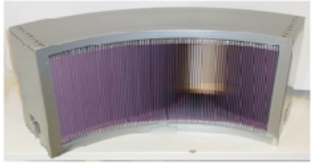
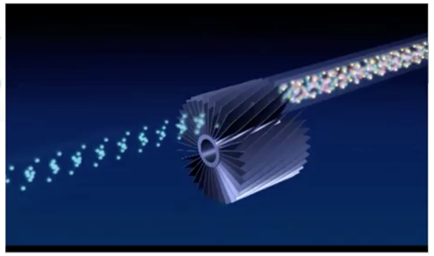
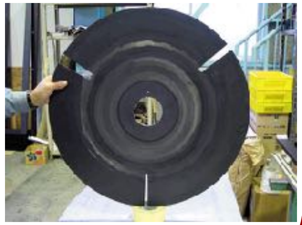






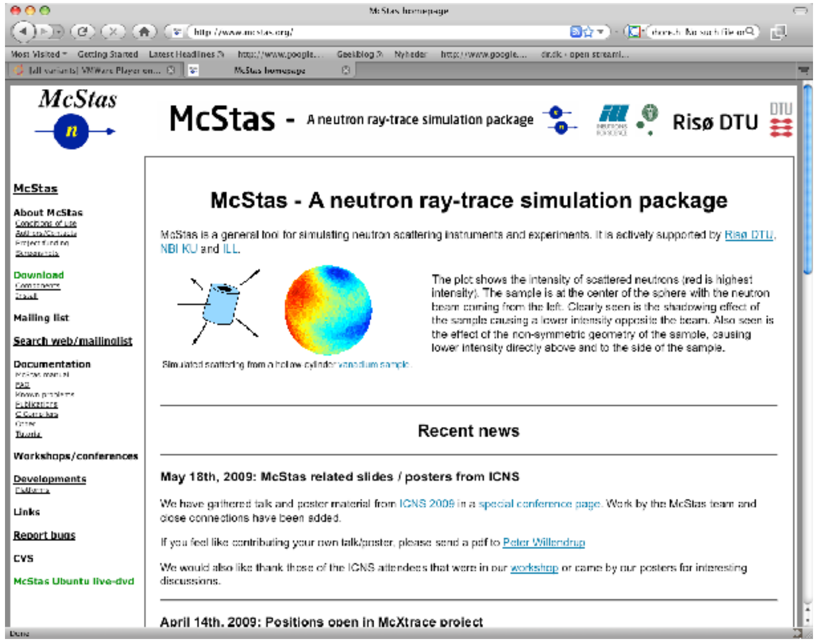
In McStas the moderator is the “source”

# McStas Introduction

- Flexible, general simulation utility for neutron scattering experiments.
- Original design for Monte carlo Simulation of triple axis spectrometers
- Developed at DTU Physics, ILL, PSI, Uni CPH, ESS DMSC
- V. 1.0 by K Nielsen & K Lefmann (1998) RISØ
- Currently ~2-3 people full time plus students and user-contributions

GNU GPL license

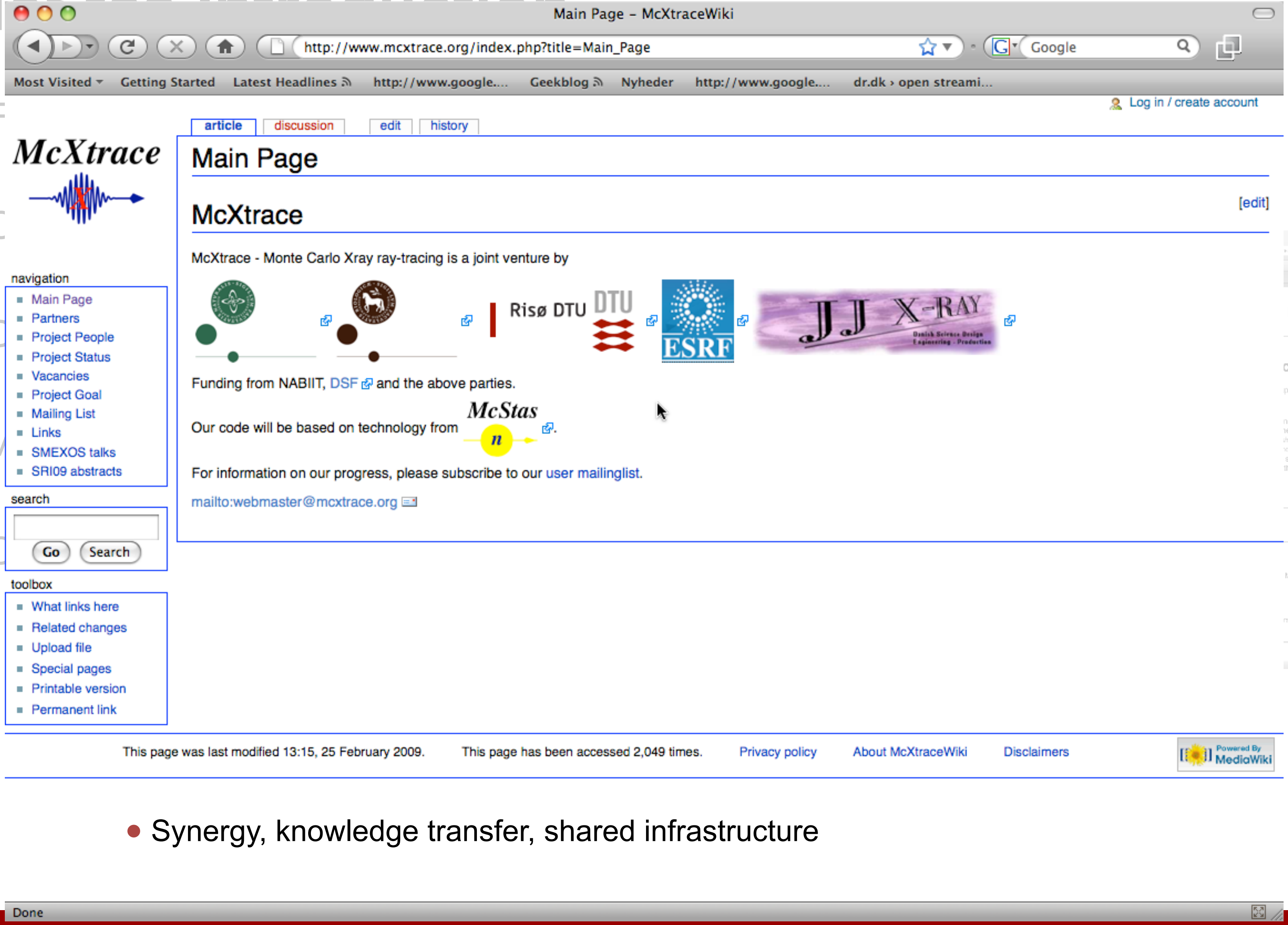
Open Source




Project website at

http://www.mcstas.org

mcstas-users@mcstas.org mailinglist



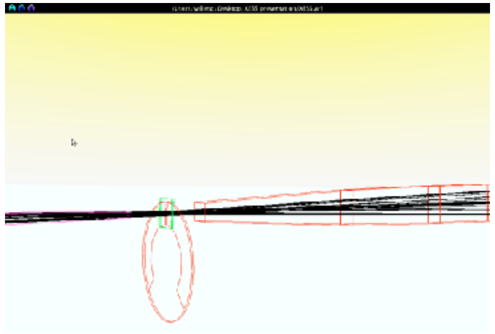
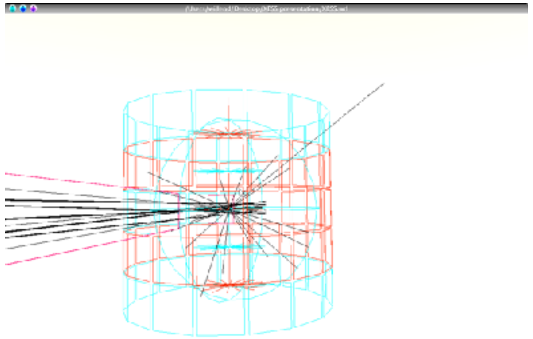
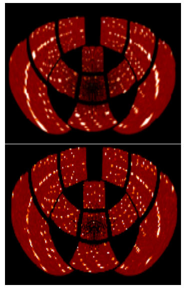
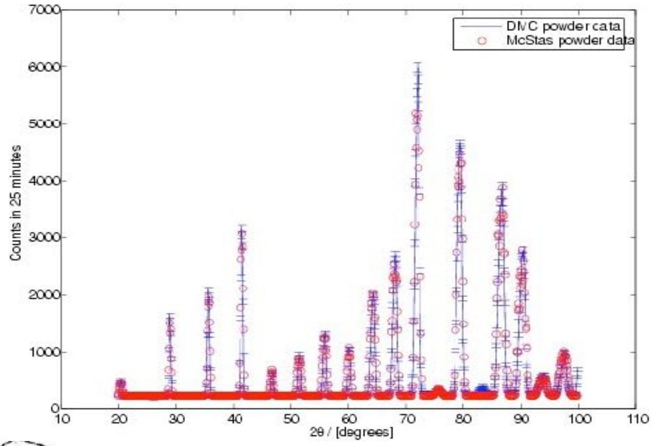

- Synergy, knowledge transfer, shared infrastructure

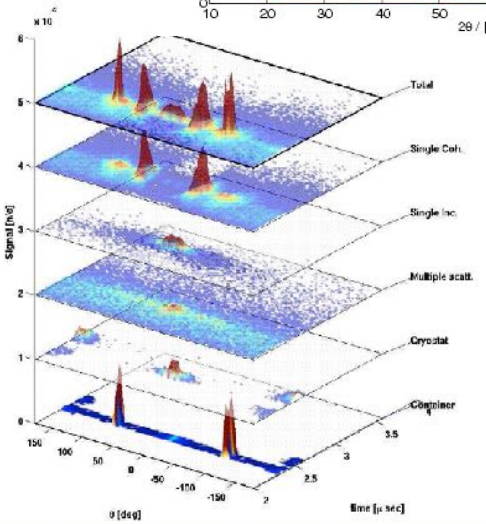
# Used in many places

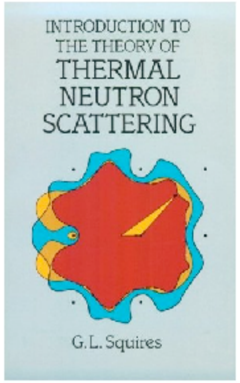
# What is McStas used for?

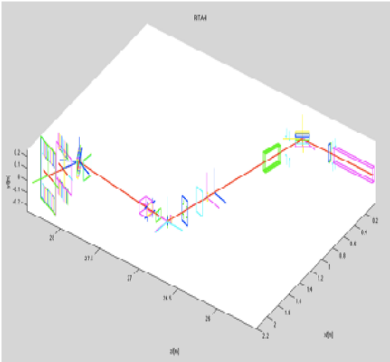
- Instrumentation
- Planning
- Construction
- Virtual experiments
- Data analysis
- Teaching

(KU, DTU)

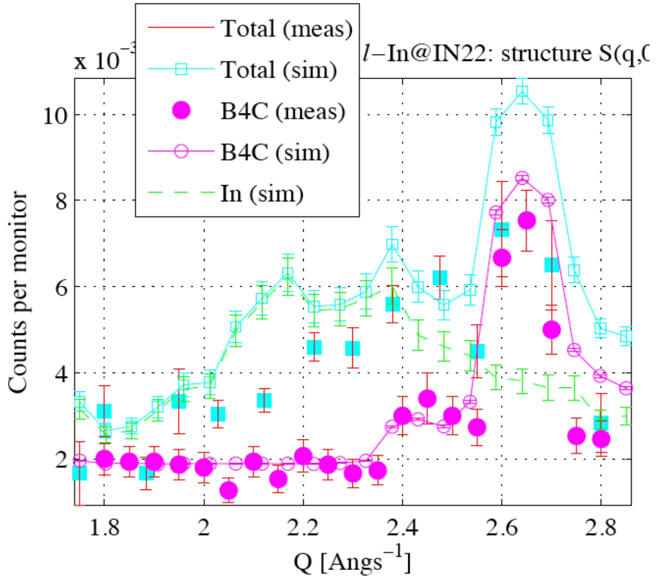




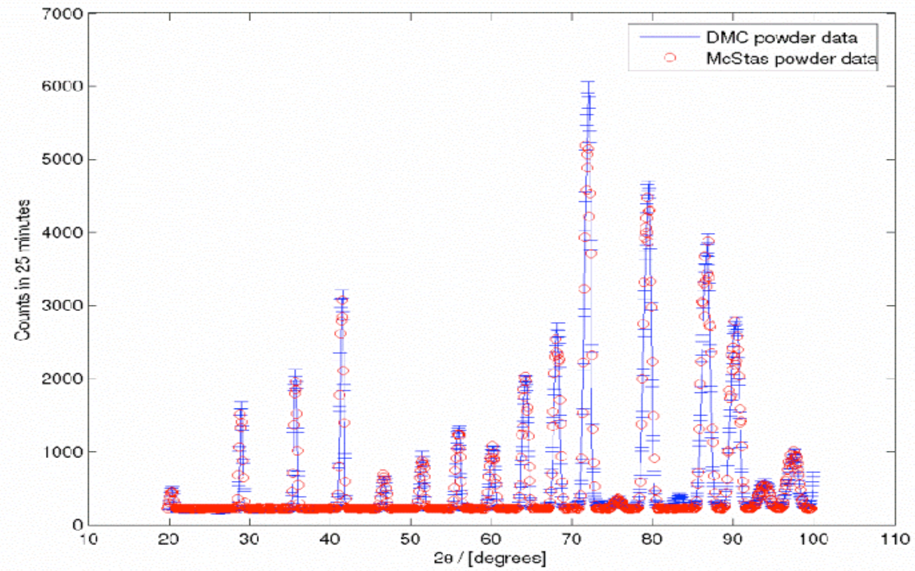



# Reliability - cross comparisons

- Much effort has gone into this
- Here: simulations vs. exp. at powder diffract. DMC, PSI
- The bottom line is
- McStas agree very well with other packages (NISP, Vitess, IDEAS, RESTRAX, ...)
- Experimental line shapes are within 5%
- Absolute intensities are within 10%
- Common understanding: McStas and similar codes are reliable




E. Farhi, P. Willendrup, from IN22 benchmark exp.




P. Willendrup et al., Physica B, 386, (2006), 1032.

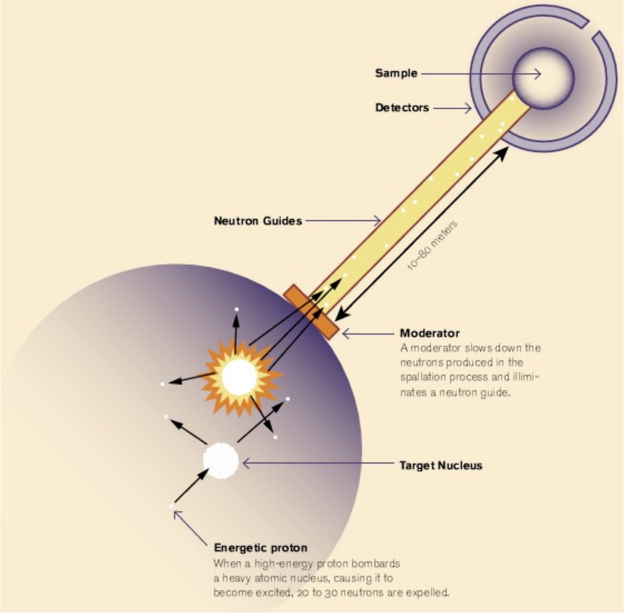
# McStas overview

CPU’s


- Portable code (Unix/Linux/Mac/Windoze)
  - Ran on everything from iPhone to 1000+ node cluster!

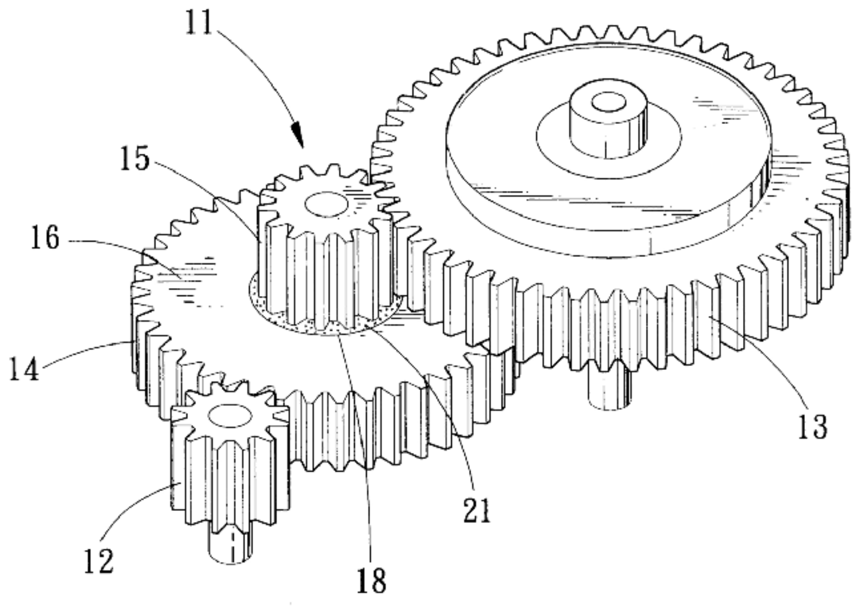
+ NVIDIA GPU’s


- 'Component' files (~100) inserted from library
  - Sources
  - Optics
  - Samples
  - Monitors
  - If needed, write your own comps
- DSL + ISO-C code gen.



# Under-the-hood / inner workings

- Domain-specific-language (DSL) based on compiler technology (LeX+Yacc)
    - Simple Instrument language $\xrightarrow{\text{Code generation}}$ ISO C
- Component codes realizing beamline parts (including user contribs)
- Library of common functions for e.g.
    - I/O
    - Random numbers
    - Physical constants
    - Propagation
    - Precession in fields
    - ...

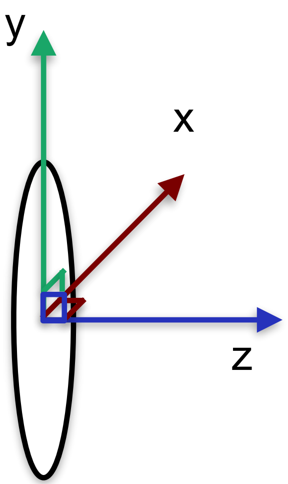


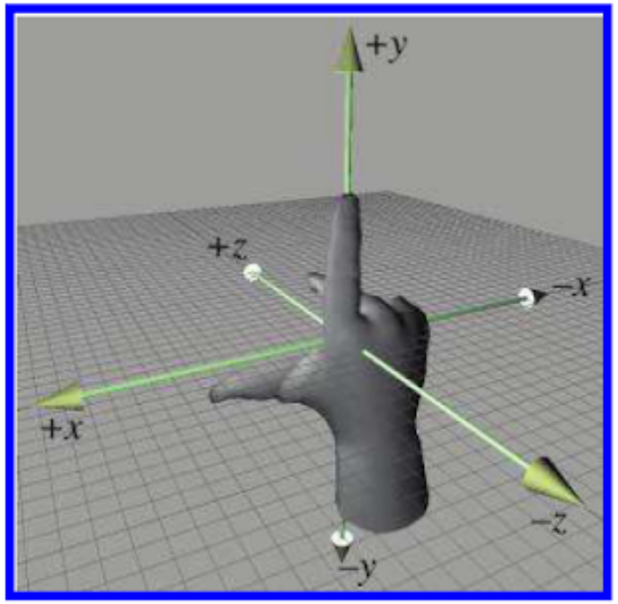
# Implementation

- Three levels of source code:
  - Instrument file (All users)
  - Component files (Some users)
  - ANSI c code (no users)

# Placing components - source

- One of the first components in your instrument is typically a source, which has a coordinate system like this….



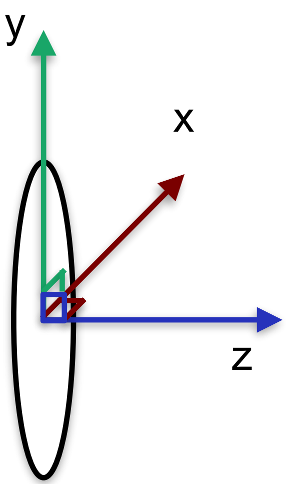

Right-handed

coordinate system

- z is along neutron beam direction
- y is vertical
- x at an angle of 90° wrt. z,y

# Placing components - source

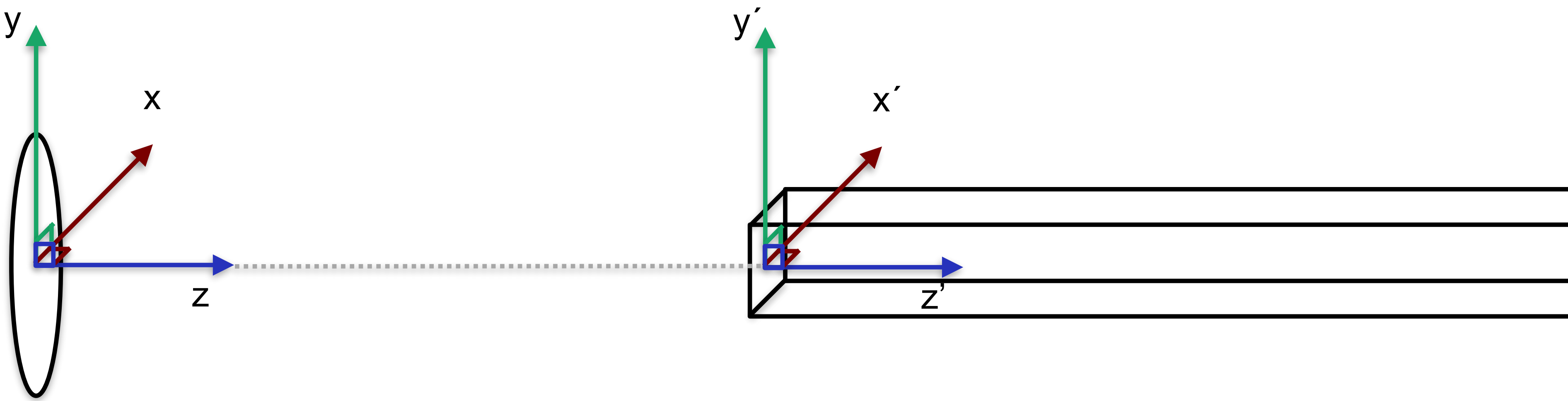
- Often the source coordinate system coincides with the “lab” coordinate system, denoted ABSOLUTE in McStas language, i.e.




- COMPONENT Source = Source_simple(…)
  AT (0,0,0) ABSOLUTE

# Placing further components - RELATIVE

Placing further components is done by order of
1. **Location, i.e**

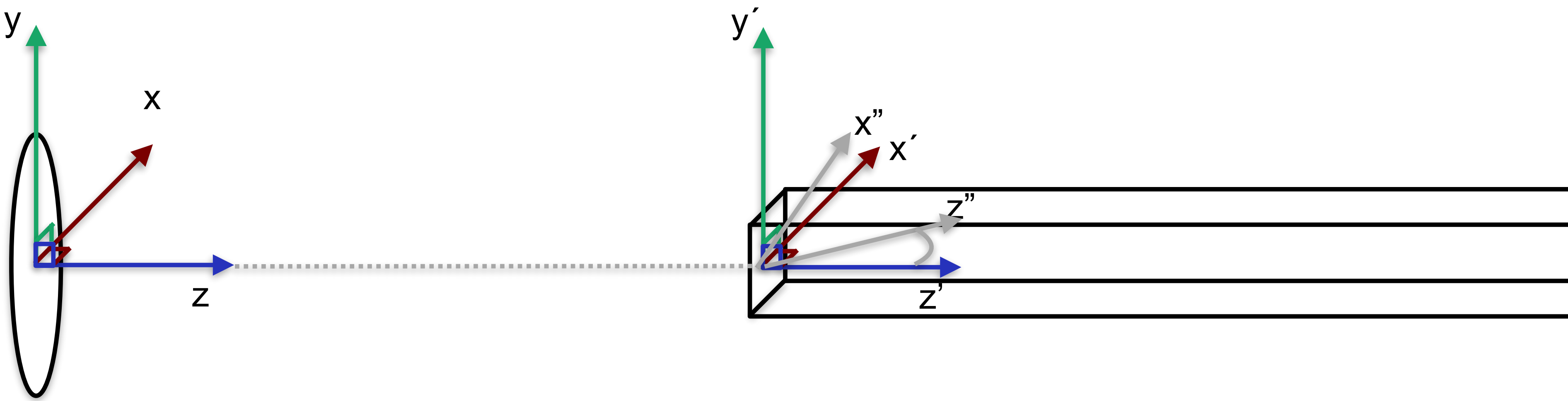



COMPONENT Source = Source_simple(…)
AT (0,0,0) ABSOLUTE

COMPONENT Guide = Guide(…)
**AT (0,0,1) RELATIVE Source**

# Placing further components - RELATIVE

Placing further components is done by order of
2. **Rotation, i.e**

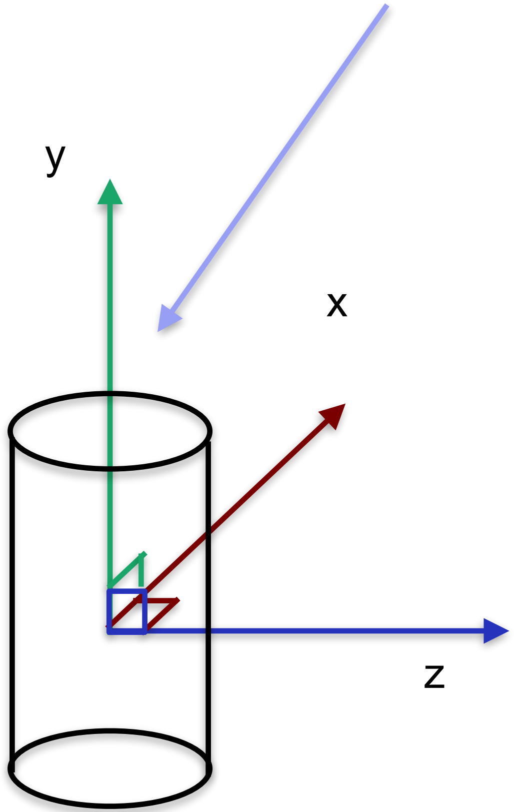


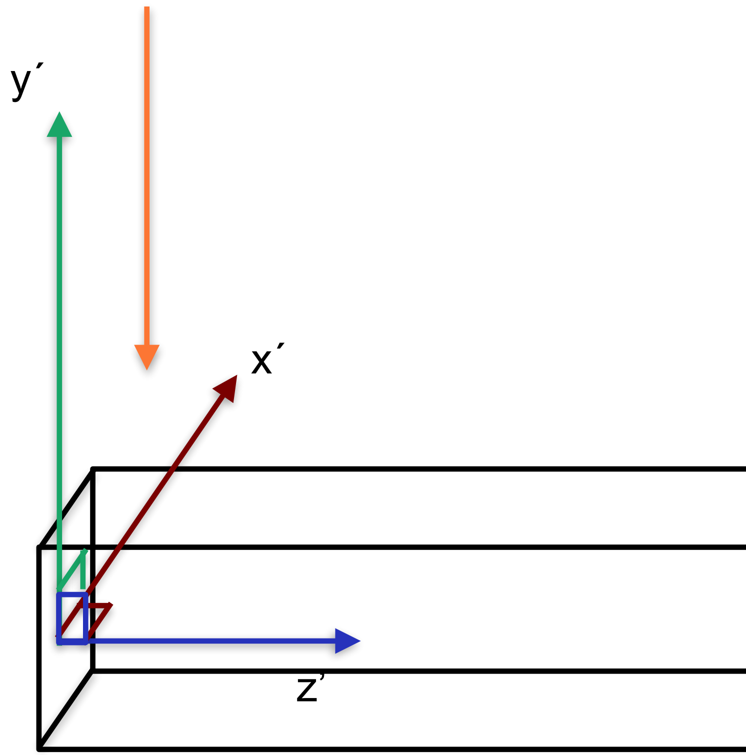

COMPONENT Source = Source_simple(…)
AT (0,0,0) ABSOLUTE

COMPONENT Guide = Guide(…)
AT (0,0,1) RELATIVE Source
**ROTATED (0,30,0) RELATIVE Source**

(Reference labels can also be PREVIOUS or PREVIOUS+1 etc.)

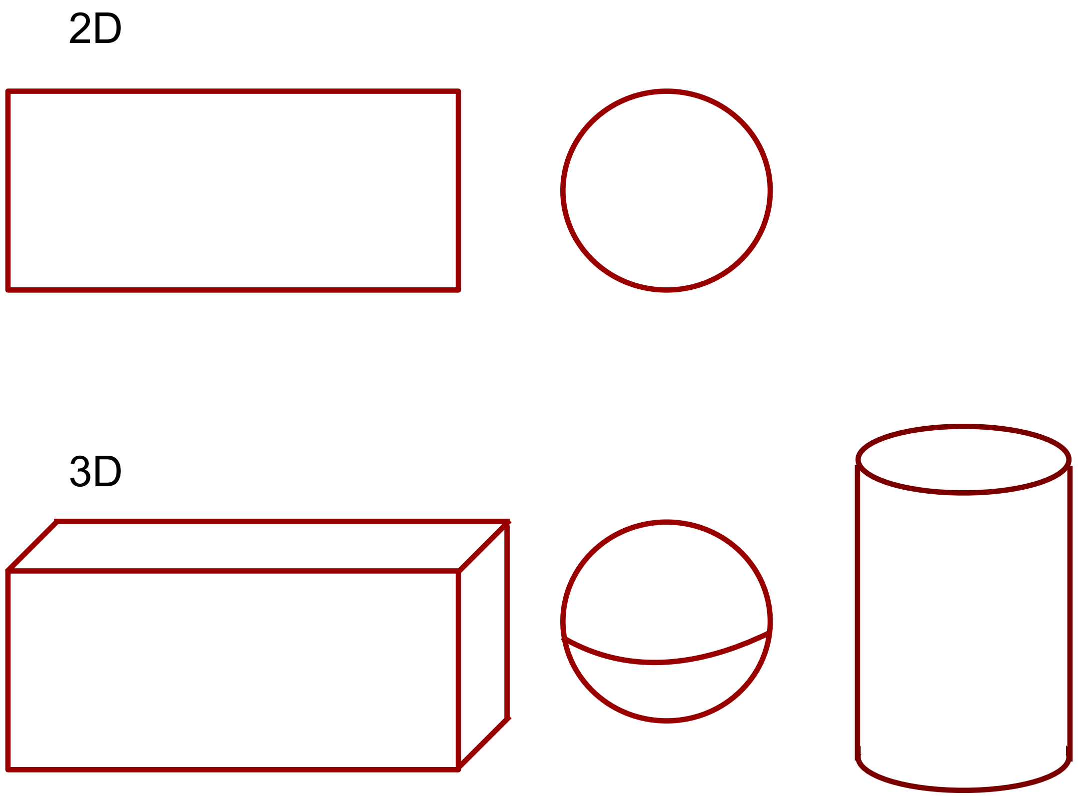
# Components often have their origin at the centre of mass, i.e. for samples … but not  for neutron guides

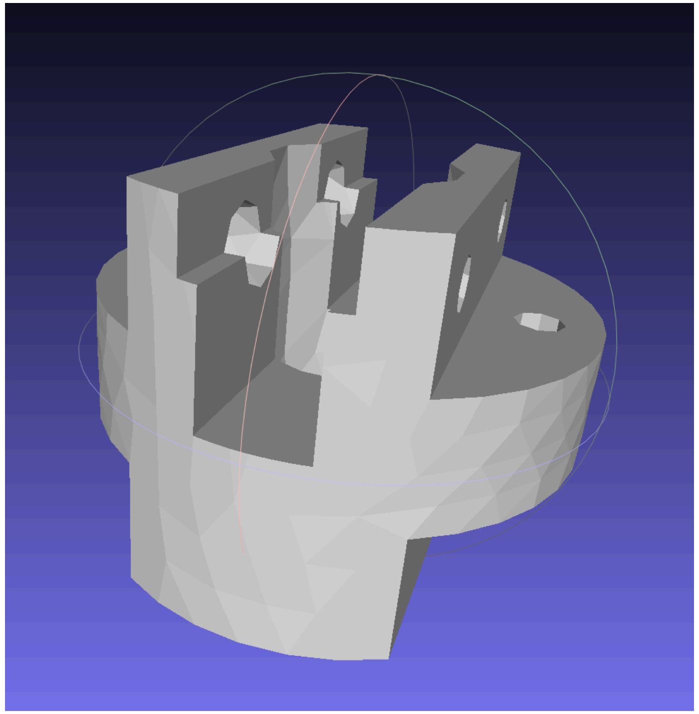


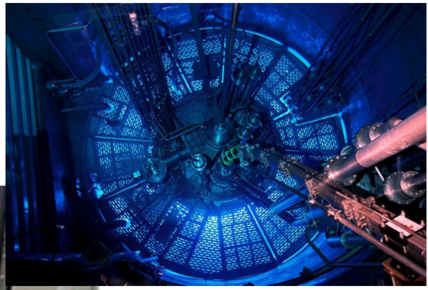

Generally speaking, the component author can choose
**the meaningful coordinate system for the given problem!**
- The McStas system takes care of the transformation between them….

# Component geometries are typically simple objects…
# But some have polygon-description of the surface



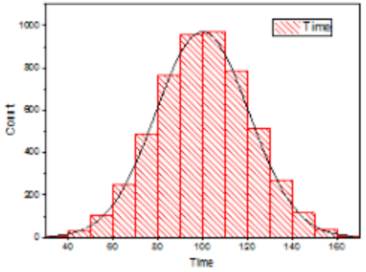
# Component classes



- Sources - these define MC starting conditions / “inject” neutrons to our simulation

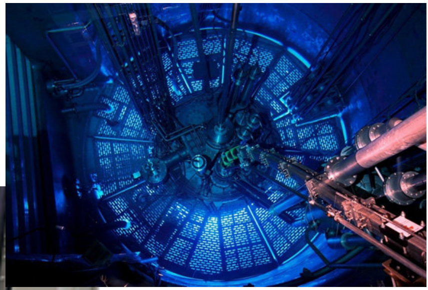

- Optics - used to tailor properties of the neutron beam
  - Examples are mirrors, guides, choppers, collimators, slits, …

- Samples - “matter” of some form
  - Powders, single crystals, liquids, micelles in solution, reflecting surfaces…
- Monitors - may probe the state of the neutron beam and store histograms / event lists




- Misc, obsolete
  - “Other stuff” and “Old stuff”


# Component classes



- Sources - these define MC starting conditions / “inject” neutrons to our simulation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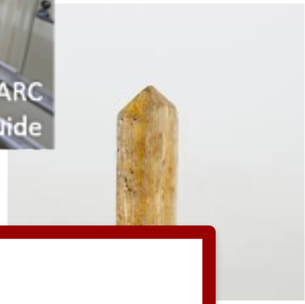


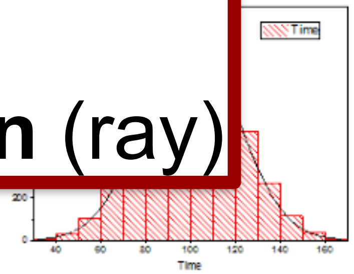
- Samples - “matter” of some form
  - Powders, single crystals, liquids, micelles in solution, reflecting surfaces

Common to all components:

They set, manipulate/interact with

or measure the **state of the neutron** (ray)

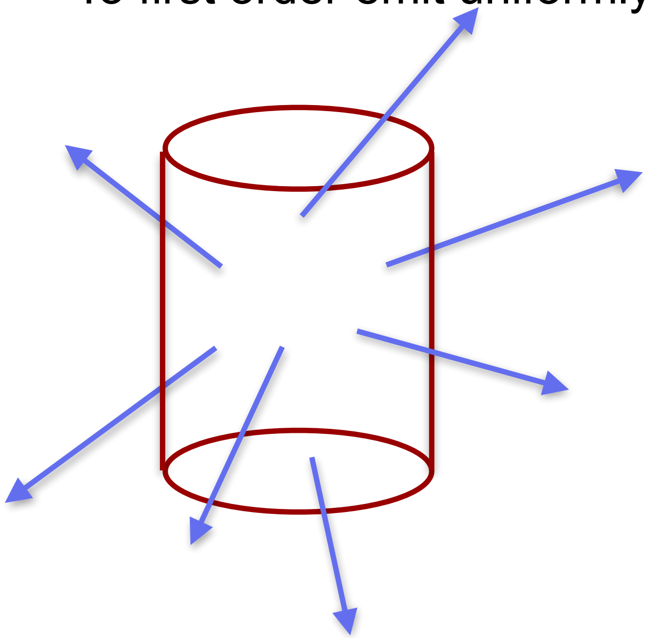
- Monitors - may probe



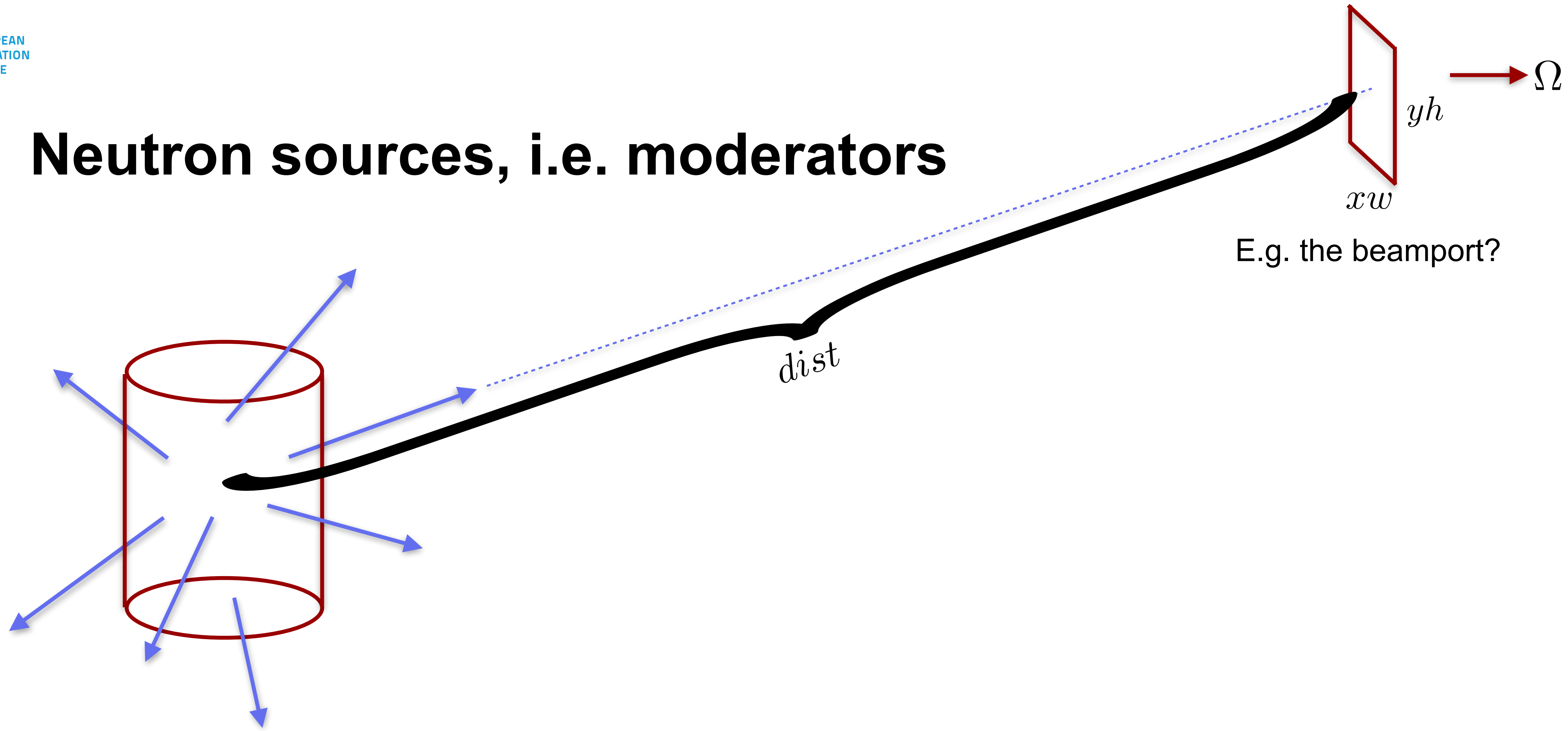

- Misc, obsolete
  - “Other stuff” and “Old stuff”


# Neutron sources, i.e. moderators

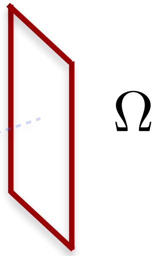
- To first order emit uniformly into $4\pi$ steradian



# Neutron sources, i.e. moderators

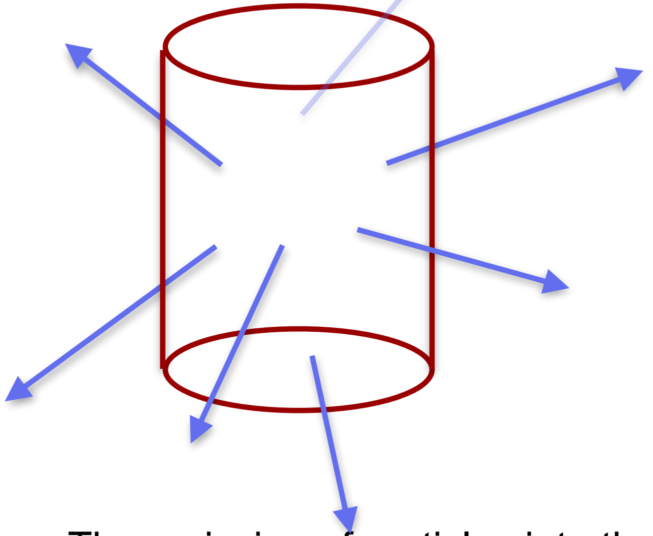



- Generally we are intersted in the input to a single instrument, characterised by a certain solid angle $\Omega$, often corresponding to a rectangle $xw$ x $yh$ at a distance $dist$ from the source




# Neutron sources, i.e. moderators

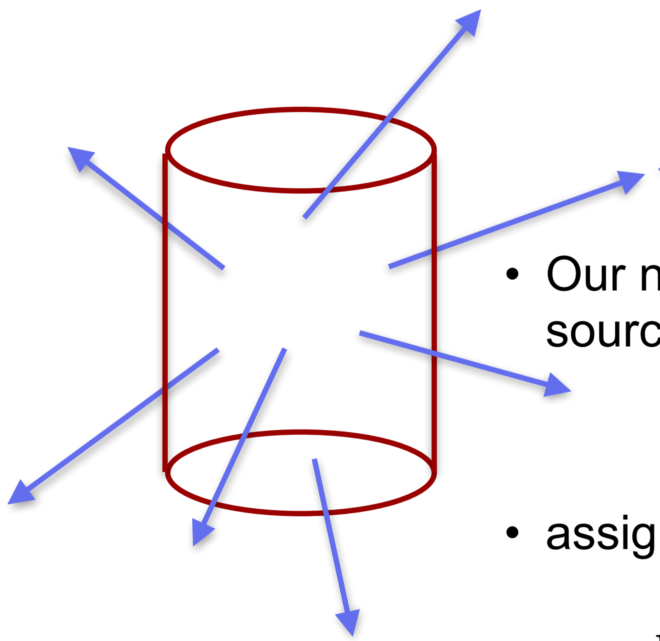
- The emmission intensity into our chosen solid angle $\Omega$ can be a function of wavelength, time (pulsed sources) and possibly point of origin on the source surface

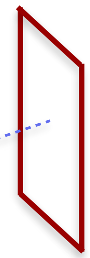


$$I(\lambda) \qquad [n/s/str]$$
$$I(\lambda, t) \qquad [n/s/str]$$
$$I(\lambda, t, \vec{r}) \qquad [n/s/str]$$

- The emission of particles into the solid angle $\Omega$ is in fact an integration and leads to a simulated "intensity" of $I_\Omega \ [n/s]$
- In McStas, that integrated intensity is partitioned over a given set of particle *rays* referred to as **ncount**, **-n** or **--ncount**
- The default **ncount** is 1e6 rays

# Neutron sources, i.e. moderators





- Our neutron rays are emitted randomly, sampling $\Omega$ and all variables of the source “spectrum”, i.e. wavelength, time and area

$$I_\Omega(\lambda, t, \vec{r}) \;\; [n/s]$$

- assigning neutron weights $p$ such that

$$\sum_{j=1}^{\mathrm{ncount}} p_j = \int_{d\lambda, dt, d\vec{r}} I_\Omega(\lambda, t, \vec{r})$$

# Neutron rays in McStas - what are they?

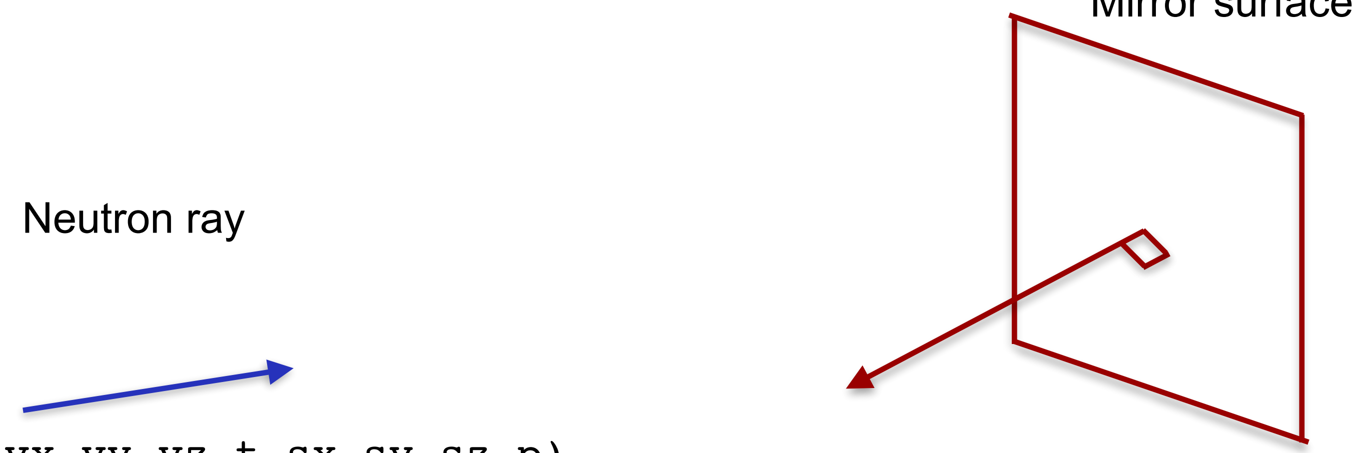
- Defining the neutron starting conditions imply setting:

  - The **starting point** on the surface, i.e. $\vec{r}$ (in the code variables `x,y,z`)
  - The **direction** into $\Omega$ and our $\lambda/E_{kin}$ (in the code variables `vx,vy,vz`)
  - The **starting time** (in the code the variable `t`)
  - The initial **intensity** / weight of the neutron ray (in the code the variable `p`)
  - If needed the initial **polarisation** (in the code the variables `sx,sy,sz`)

| Neutron **ray** in McStas: | |
|---|---|
| Location | `x,y,z` |
| Velocity | `vx,vy,vz` |
| Time | `t` |
| Polarisation. | `sx,sy,sz` |
| Intensity | `p` |

# Neutron (ray)-matter interaction 1: reflecting surface

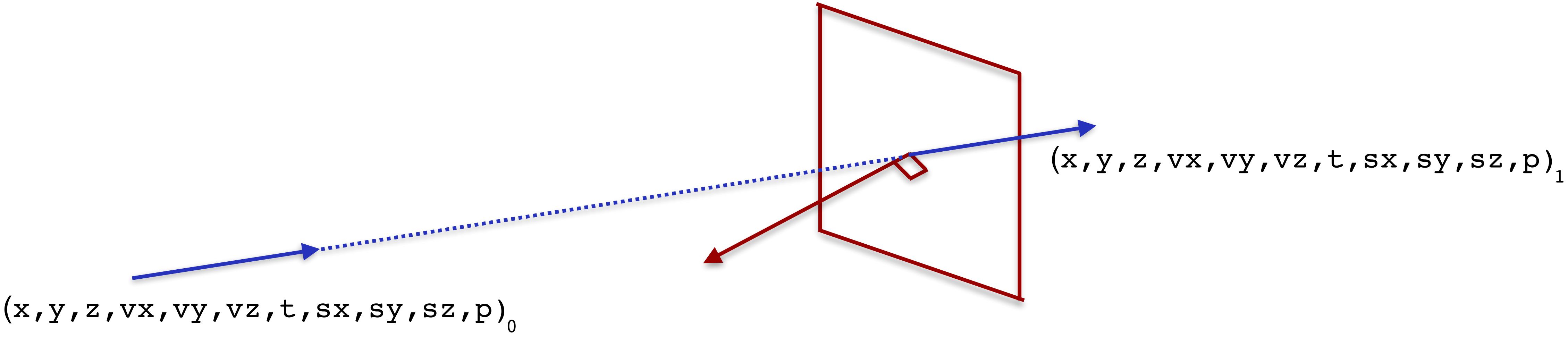
- 1 starting situation




$(x,y,z,vx,vy,vz,t,sx,sy,sz,p)_0$

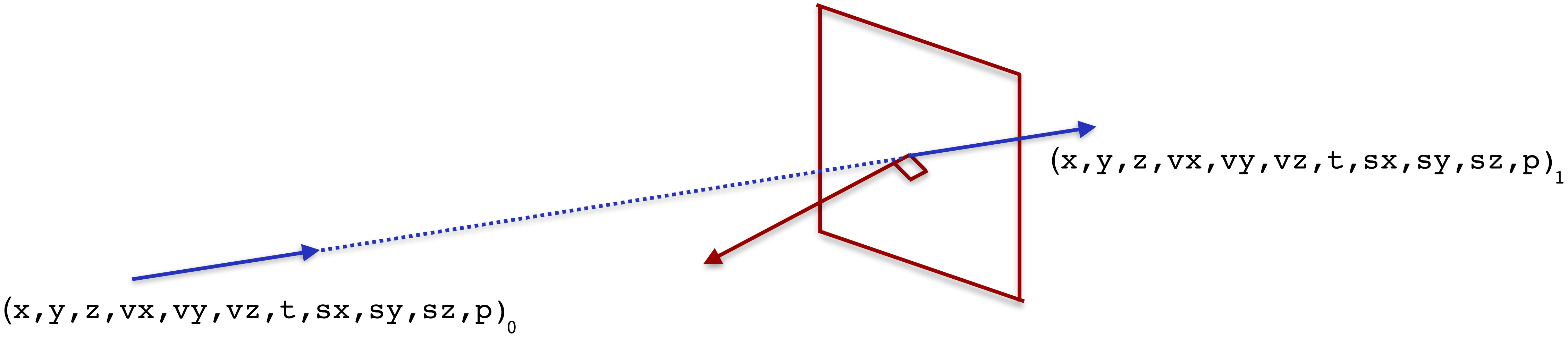
# Neutron (ray)-matter interaction 1: reflecting surface

- 2. Propagate to the mirror surface



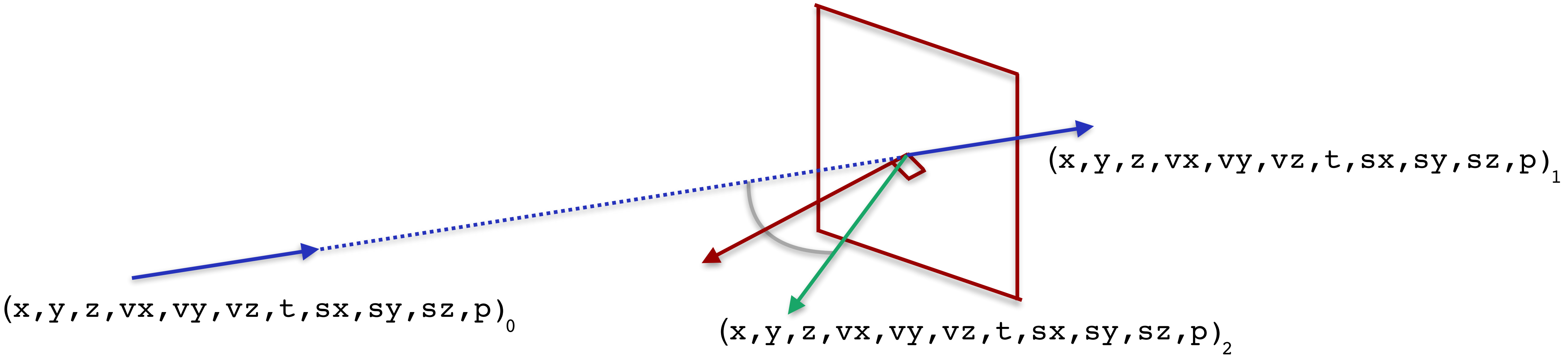
# Neutron (ray)-matter interaction 1: reflecting surface

- 3. Checks (are we on surface, what is probability of reflection etc.)



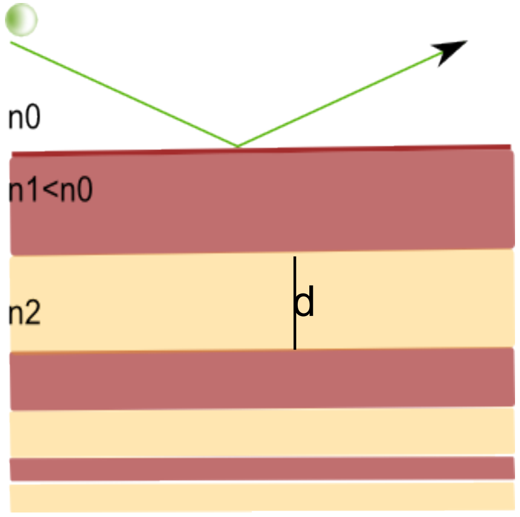
# Neutron (ray)-matter interaction 1: reflecting surface

- 4. Reflect




**Weight of final ray is adjusted according to reflectivity, see next slide**

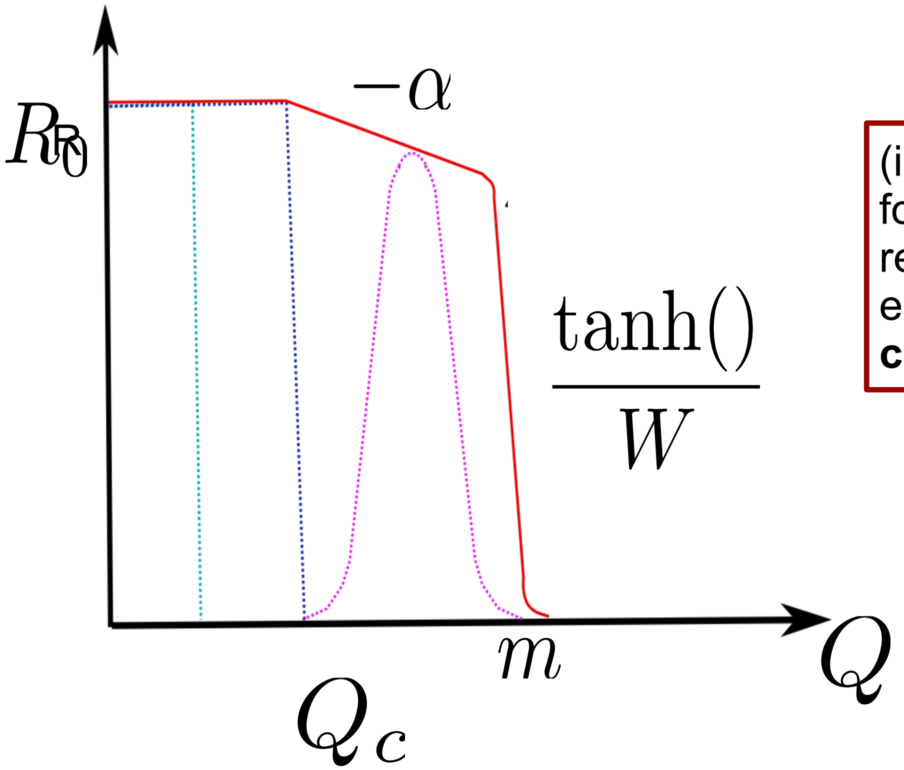
# Parametrisation of reflectivity on mirrors etc.




$$V = \frac{2\pi\hbar^2}{m} bN \quad \sin\theta < \sqrt{\frac{mV}{2\pi^2\hbar^2}}\lambda$$

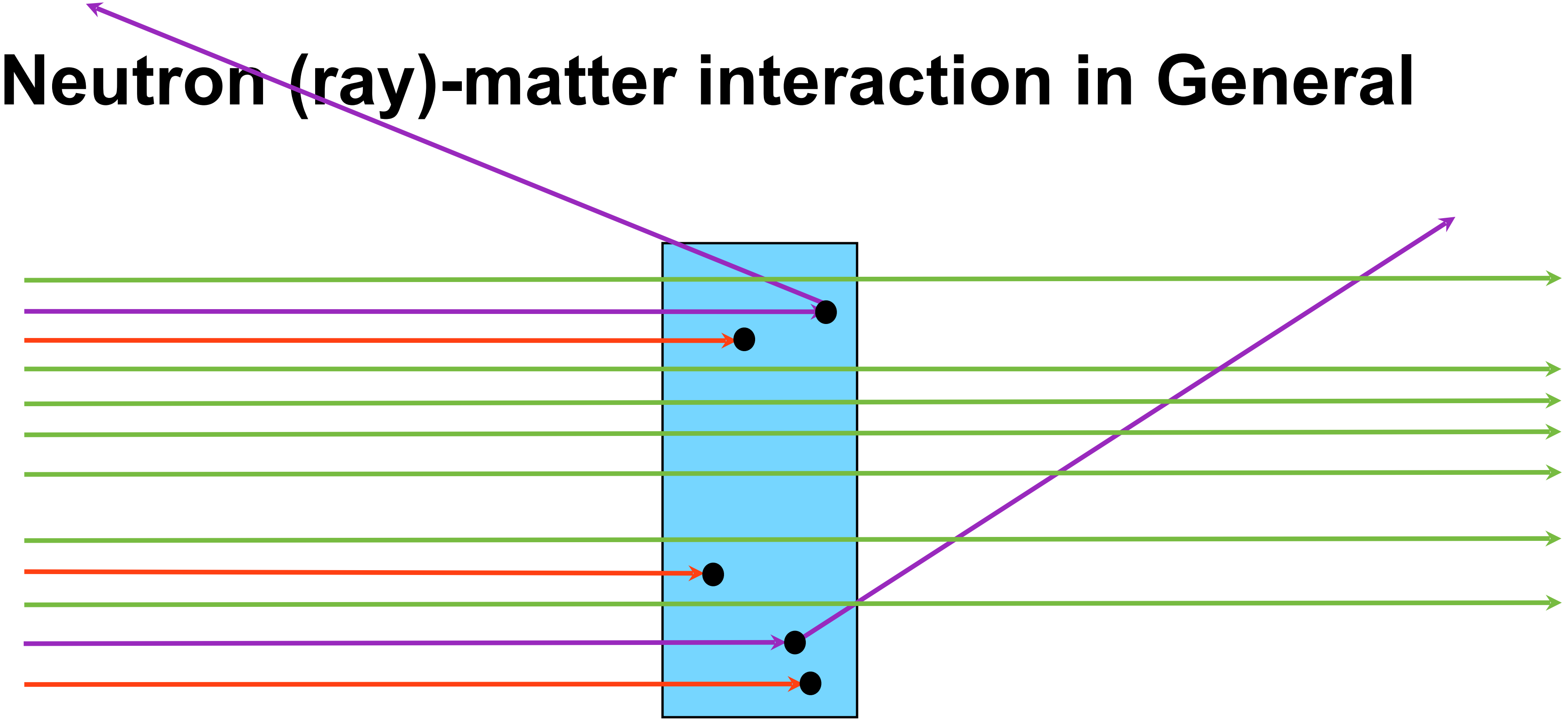
$$m = \frac{\theta_{mirror}}{\theta_{Ni}}$$

$$R_0 \cdot \left(1 - \frac{\tanh\left(Q - mQ_c\right)}{W}\right) \cdot \left(1 - \alpha\left(Q - Q_c\right)\right)$$




(i.e. Q is calculated for given neutron, reflectivity encoded in **changed *p* value**)

# Neutron (ray)-matter interaction in General



A neutron hitting a sample can be:
absorbed, transmitted, or scattered

# Samples

For a **non-thin** sample the probabilities for absorption, transmission or scattering are given by

$$\boxed{p_A = (1 - e^{-\Sigma_T t})(\Sigma_A / \Sigma_T)}$$

$$\boxed{p_S = (1 - e^{-\Sigma_T t})(\Sigma_S / \Sigma_T)}$$

$$\boxed{p_T = 1 - p_S - p_A = e^{-\Sigma_T t}}$$

**t =** sample thickness

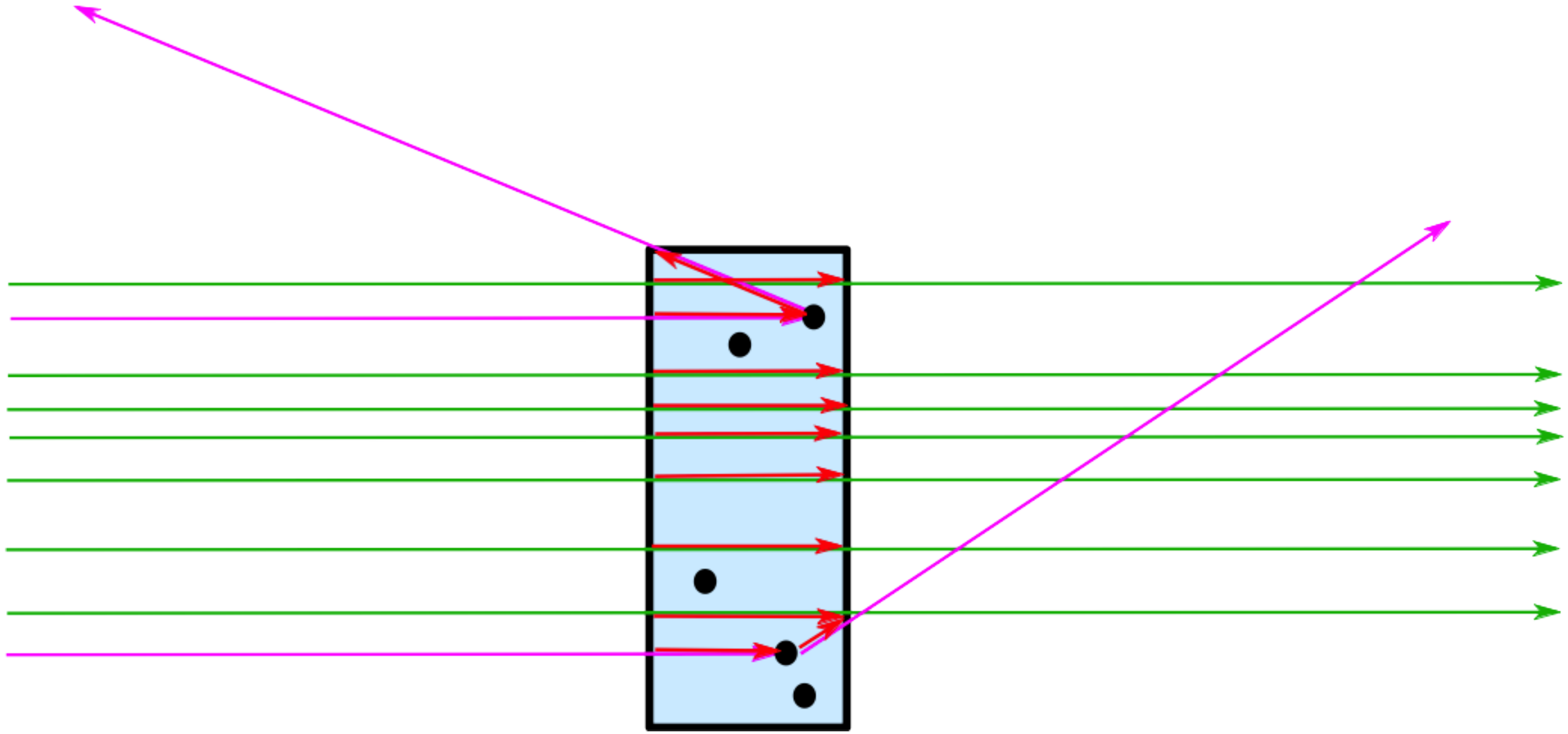
$$\Sigma_* = \rho \sigma_*$$

macroscopic cross section [cm$^{-1}$]

number density [atoms/cm$^3$]

microscopic cross section [barn/atom]
1 barn = $10^{-24}$cm$^2$

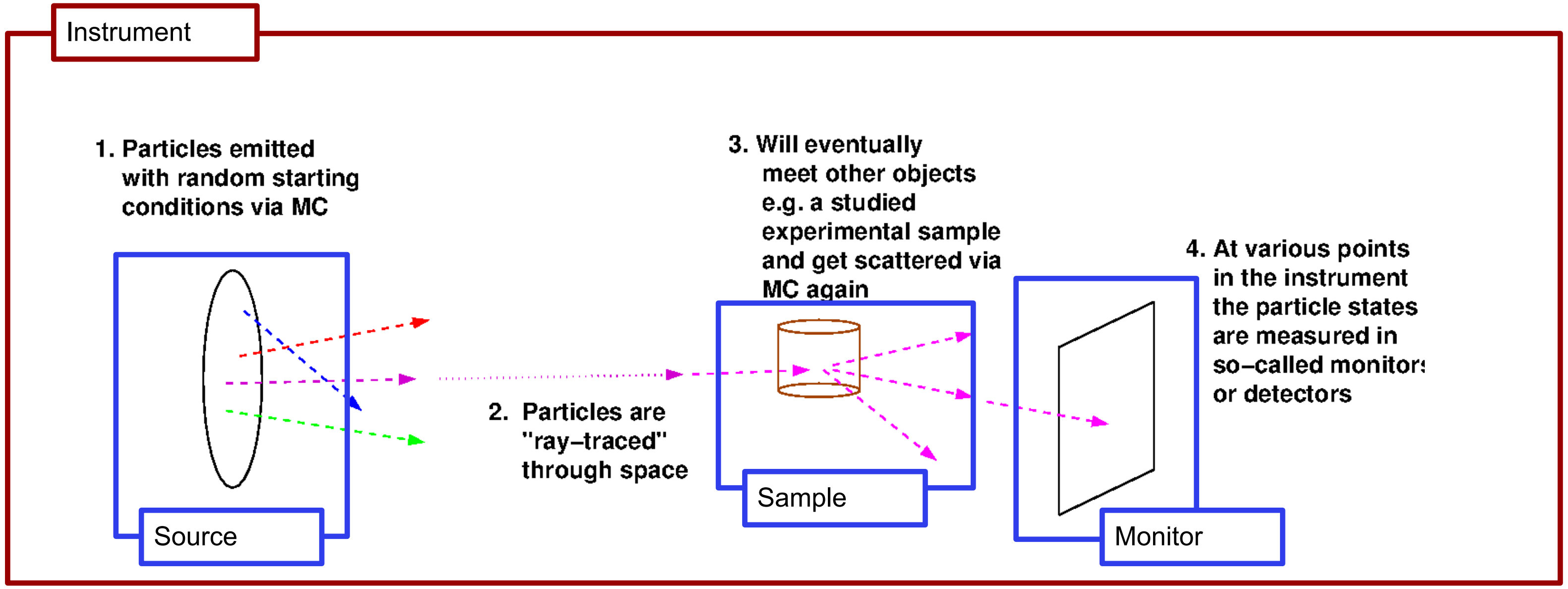
# Samples/Matter interaction in General in McStas



A neutron ray hitting a sample can be:
transmitted+absorption, or scattered+absorption

# Transport of weight through the instrument…

In a given component, the neutron intensity is adjusted by a multiplicative factor (probability)




$p_0$ $\qquad p_j$ $\qquad p_n$

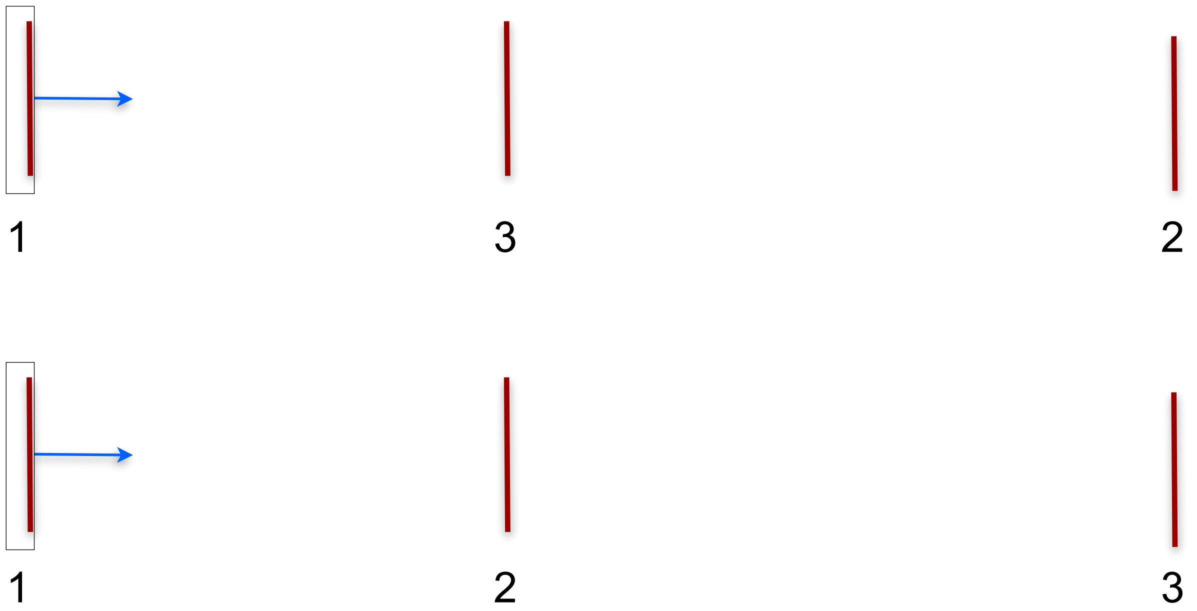
$$p_j = w_j p_{j-1}$$

$$p_j = p_0 \prod_{k=1}^{j} w_k$$

The weight multiplier of the j'th component, $w_j$, is calculated by the probability rule $f_{\mathrm{MC,b}} w_j = P_{\mathrm{b}}$ where Pb is the physical probability for the event "b", and $f_{MC,b}$ is the probability that the Monte Carlo simulation selects this event.

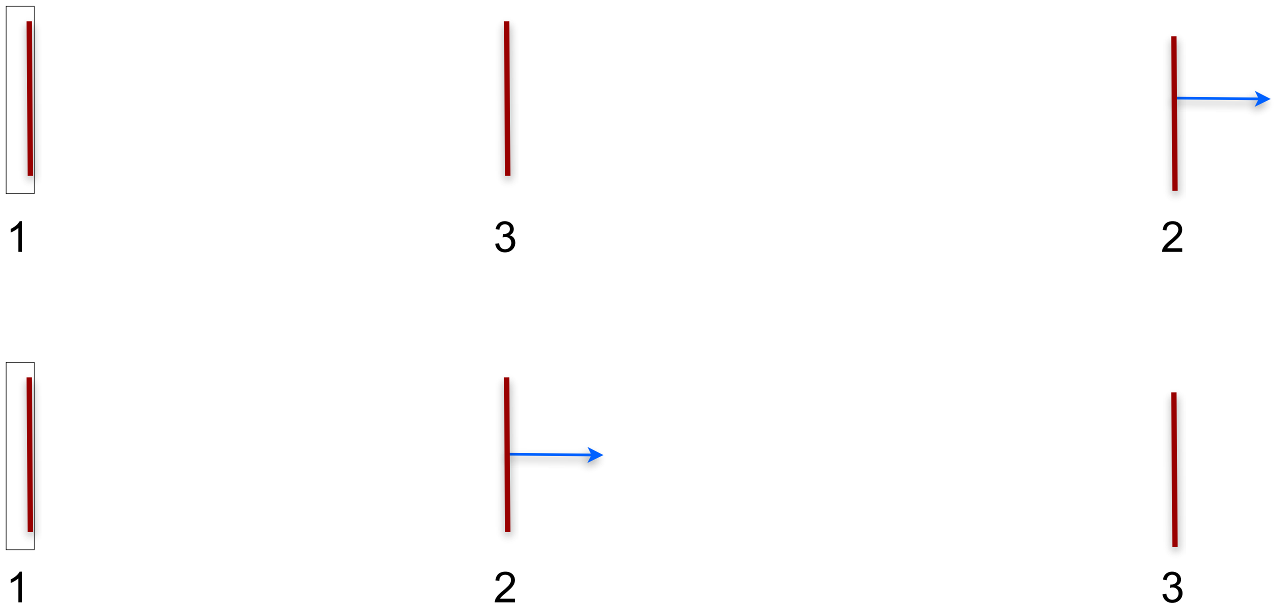
In case of "branching", i.e. multiple outcomes, it is clear that $\sum_b f_{\mathrm{MC,b}} = 1$

# To first order, McStas is linear and follows sequence of components in your file…



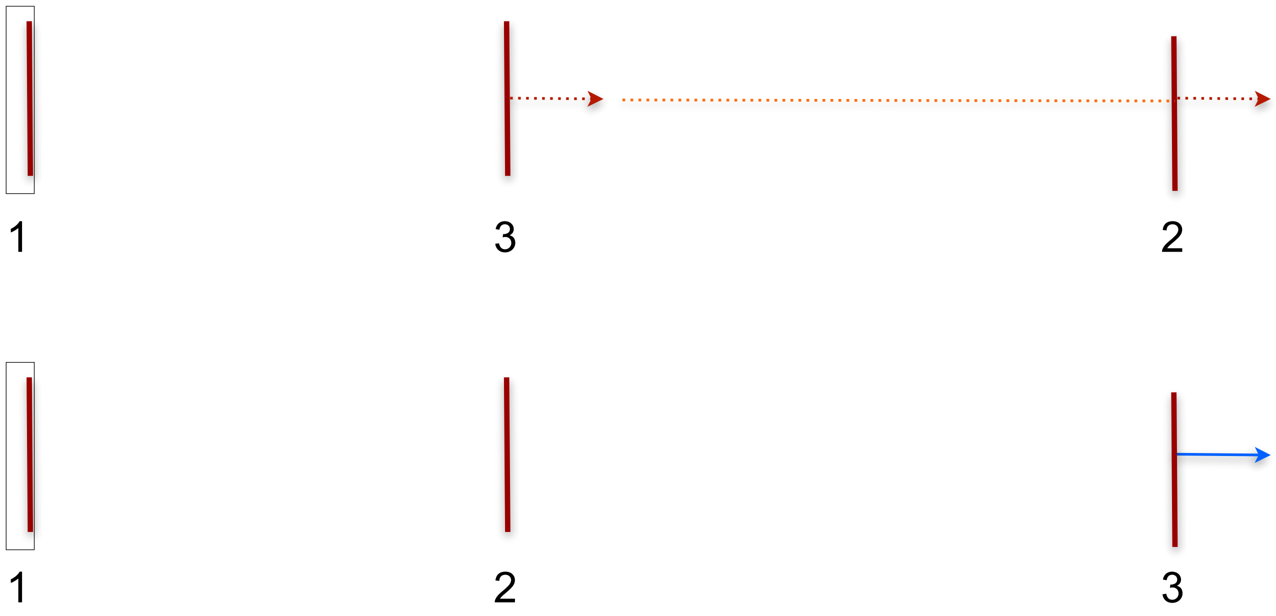

Starting at the source

# To first order, McStas is linear and follows sequence of components in your file…




Moving to first comp in the list

# To first order, McStas is linear and follows sequence of components in your file…



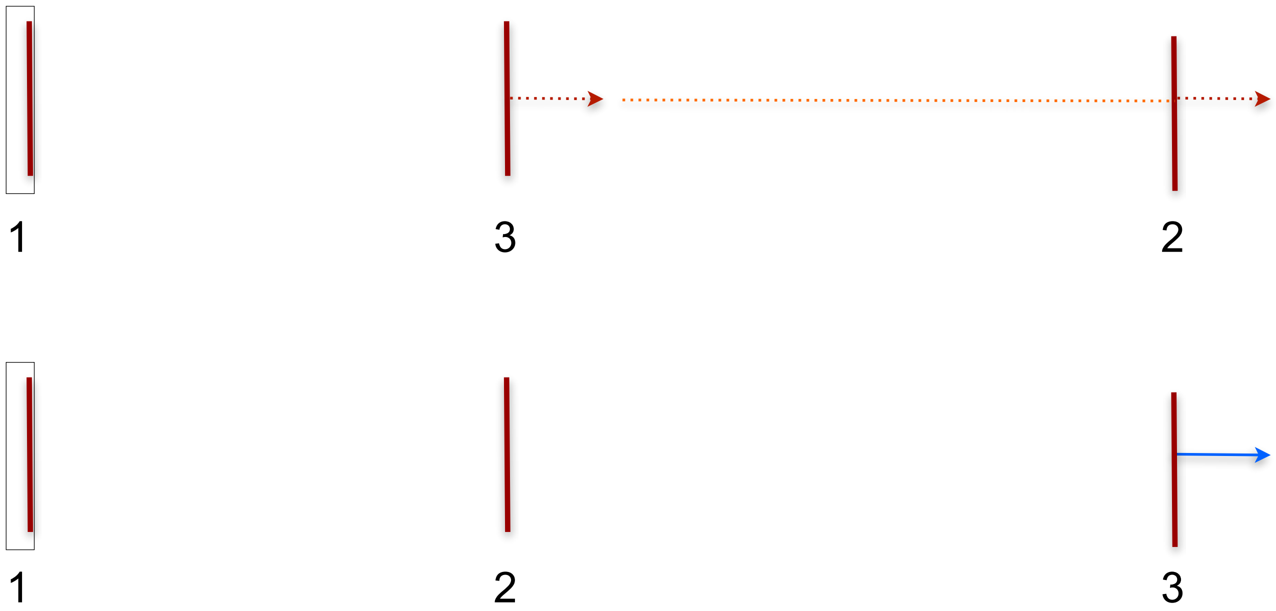

Moving to 3rd comp in list requires “moving back in time”.

Default behavior is to ABSORB this type of neutron.

For monitors use restore_neutron=1 in this case.

For homegrown comps use ALLOW_BACKPROP macro.

# To first order, McStas is linear and follows sequence of components in your file…




The order of components is important,

and in general overlaps should be avoided!

Moving to 3rd comp in list requires “moving back in time”.

Default behavior is to ABSORB this type of neutron.

For monitors use restore_neutron=1 in this case.

For homegrown comps use ALLOW_BACKPROP macro.

# Instrument file

```
DEFINE INSTRUMENT My_Instrument(DIST=10)

/* Here comes the TRACE section, where the actual      */
/* instrument is defined as a sequence of components.  */
TRACE

/* The Arm() class component defines reference points and orientations  */
/* in 3D space.                                                          */
COMPONENT Origin = Arm()
  AT (0,0,0) ABSOLUTE


COMPONENT Source = Source_simple(
    radius = 0.1, dist = 10, xw = 0.1, yh = 0.1, E0 = 5, dE = 1)
  AT (0, 0, 0) RELATIVE Origin


COMPONENT Emon = E_monitor(
    filename = "Emon.dat", xmin = -0.1, xmax = 0.1, ymin = -0.1,
    ymax = 0.1, Emin = 0, Emax = 10)
  AT (0, 0, DIST) RELATIVE Origin


COMPONENT PSD = PSD_monitor(
    nx = 128, ny = 128, filename = "PSD.dat", xmin = -0.1,
    xmax = 0.1, ymin = -0.1, ymax = 0.1)
  AT (0, 0, 1e-10) RELATIVE Emon

/* The END token marks the instrument definition end */
END
```

Written by you!

# Component file

```
/*******************************************************************************
*
* Mcstas, neutron ray-tracing package
*         Copyright 1997-2002, All rights reserved
*         Risoe National Laboratory, Roskilde, Denmark
*         Institut Laue Langevin, Grenoble, France
*
* Component: Source_flat
*
* %I
* Written by: Kim Lefmann
* Date: October 30, 1997
* Modified by: KL, October 4, 2001
* Modified by: Emmanuel Farhi, October 30, 2001. Serious bug corrected.
* Version: $Revision: 1.22 $
* Origin: Risoe
* Release: McStas 1.6
*
* A circular neutron source with flat energy spectrum and arbitrary flux
*
* %D
* The routine is a circular neutron source, which aims at a square target
* centered at the beam (in order to improve MC-acceptance rate).  The angular
* divergence is then given by the dimensions of the target.
* The neutron energy is uniformly distributed between E0-dE and E0+dE.
*
* Example: Source_flat(radius=0.1, dist=2, xw=.1, yh=.1, E0=14, dE=2)
*
* %P
* radius: (m)   Radius of circle in (x,y,0) plane where neutrons
*               are generated.
* dist:   (m)   Distance to target along z axis.
* xw:     (m)   Width(x) of target
* yh:     (m)   Height(y) of target
* E0:     (meV) Mean energy of neutrons.
* dE:     (meV) Energy spread of neutrons.
* Lambda0 (AA)  Mean wavelength of neutrons.
* dLambda (AA)  Wavelength spread of neutrons.
* flux    (1/(s*cm**2*st)) Energy integrated flux
*
* %E
*******************************************************************************/

DEFINE COMPONENT Source_simple
DEFINITION PARAMETERS ()
SETTING PARAMETERS (radius, dist, xw, yh, E0=0, dE=0, Lambda0=0, dLambda=0, flux=1)
OUTPUT PARAMETERS ()
STATE PARAMETERS (x,y,z,vx,vy,vz,t,s1,s2,p)
DECLARE
%{
  double pmul, pdir;
%}
INITIALIZE
%{
  pmul=flux*PI*1e4*radius*radius/mcget_ncount();
%}
```

```
TRACE
%{
 double chi,E,Lambda,v,r, xf, yf, rf, dx, dy;

 t=0;
 z=0;

 chi=2*PI*rand01();                          /* Choose point on source */
 r=sqrt(rand01())*radius;                    /* with uniform distribution. */
 x=r*cos(chi);
 y=r*sin(chi);

 randvec_target_rect(&xf, &yf, &rf, &pdir,
        0, 0, dist, xw, yh, ROT_A_CURRENT_COMP);

 dx = xf-x;
 dy = yf-y;
 rf = sqrt(dx*dx+dy*dy+dist*dist);

 p = pdir*pmul;

 if(Lambda0==0) {
   E=E0+dE*randpm1();              /*  Choose from uniform distribution */
   v=sqrt(E)*SE2V;
 } else {
   Lambda=Lambda0+dLambda*randpm1();
   v = K2V*(2*PI/Lambda);
 }

 vz=v*dist/rf;
 vy=v*dy/rf;
 vx=v*dx/rf;
%}

MCDISPLAY
%{
  magnify("xy");
  circle("xy",0,0,0,radius);
%}

END
```

Written by developers and possibly you!

# Generated c-code

```
/* Automatically generated file. Do not edit.
 * Format:     ANSI C source code
 * Creator:    McStas <http://neutron.risoe.dk>
 * Instrument: My_Instrument.instr (My_Instrument)
 * Date:       Sat Apr  9 15:27:56 2005
 */

/* THOUSANDS of lines removed here.... */

  /* TRACE Component Source. */
  SIG_MESSAGE("Source (Trace)");
  mcDEBUG_COMP("Source")
  mccoordschange(mcposrSource, mcrotrSource,
    &mcnlx, &mcnly, &mcnlz,
    &mcnlvx, &mcnlvy, &mcnlvz,
    &mcnlt, &mcnlsx, &mcnlsy);
  mcDEBUG_STATE(mcnlx, mcnly, mcnlz, mcnlvx, mcnlvy, mcnlvz,mcnlt,mcnlsx,mcnlsy, mcnlp)
#define x mcnlx
#define y mcnly
#define z mcnlz
#define vx mcnlvx
#define vy mcnlvy
#define vz mcnlvz
#define t mcnlt
#define s1 mcnlsx
#define s2 mcnlsy
#define p mcnlp
  STORE_NEUTRON(2,mcnlx, mcnly, mcnlz, mcnlvx,mcnlvy,mcnlvz,mcnlt,mcnlsx,mcnlsy, mcnlsz, mcnlp);
  mcScattered=0;
  mcNCounter[2]++;
#define mccompcurname Source
#define mccompcurindex 2
{   /* Declarations of SETTING parameters. */
MCNUM radius = mccSource_radius;
MCNUM dist = mccSource_dist;
MCNUM xw = mccSource_xw;
MCNUM yh = mccSource_yh;
MCNUM E0 = mccSource_E0;
MCNUM dE = mccSource_dE;
MCNUM Lambda0 = mccSource_Lambda0;
MCNUM dLambda = mccSource_dLambda;
MCNUM flux = mccSource_flux;
#line 58 "Source_simple.comp"
{
 double chi,E,Lambda,v,r, xf, yf, rf, dx, dy;

 t=0;
 z=0;

 chi=2*PI*rand01();                          /* Choose point on source */
 r=sqrt(rand01())*radius;                    /* with uniform distribution. */
 x=r*cos(chi);
 y=r*sin(chi);

 randvec_target_rect(&xf, &yf, &rf, &pdir,
        0, 0, dist, xw, yh, ROT_A_CURRENT_COMP);
```

Written by mcstas!

McStas is a (pre)compiler!

Input is .comp and .instr files + runtime functions for e.g. random numbers

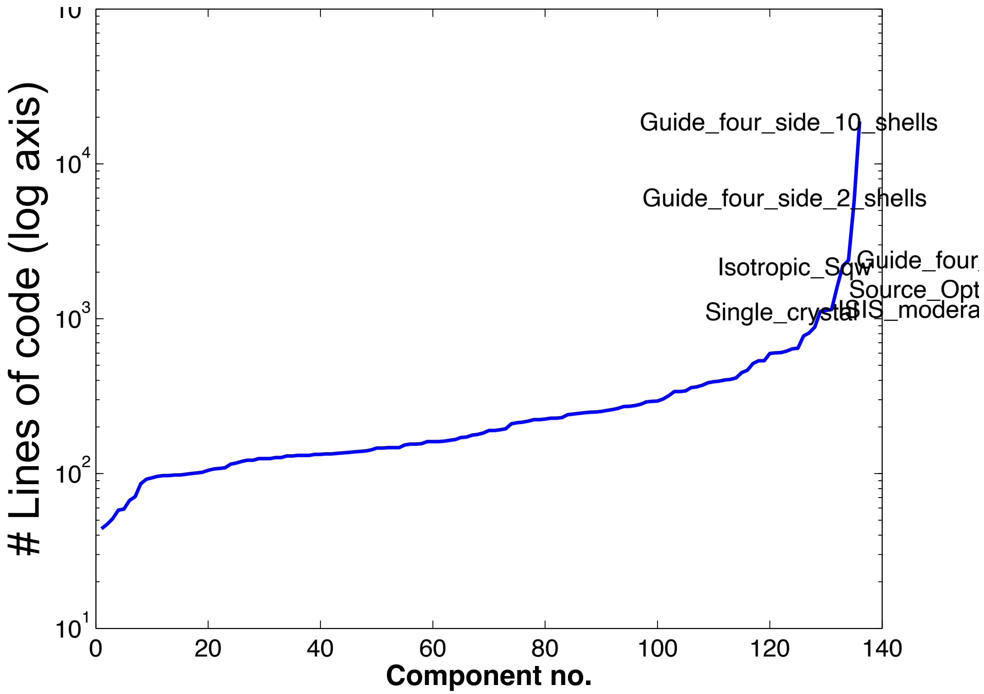
Output is a single c-file, which can be compiled using e.g. gcc.

Can take input arguments if needed.

# Writing new comps or understanding existing is not that complex...

- Check our long list of components and look inside... Most of them are quite simple and short... Statistics:

**Number of lines of code per component - 240 comps in total**

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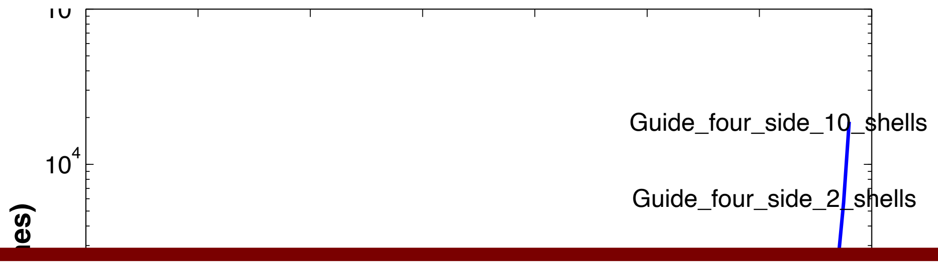
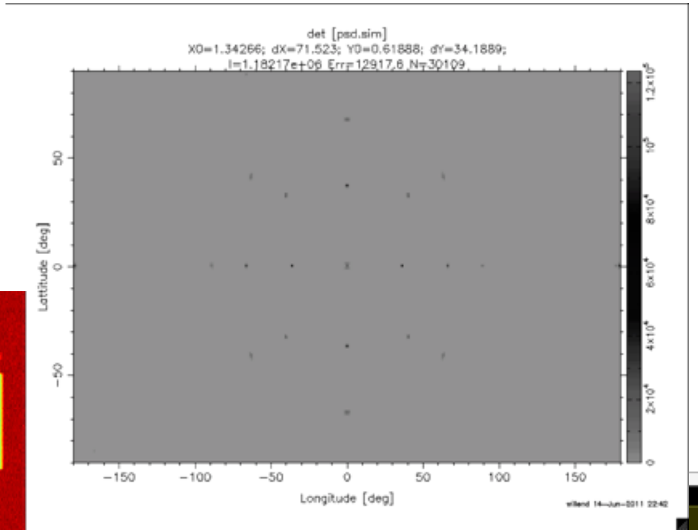
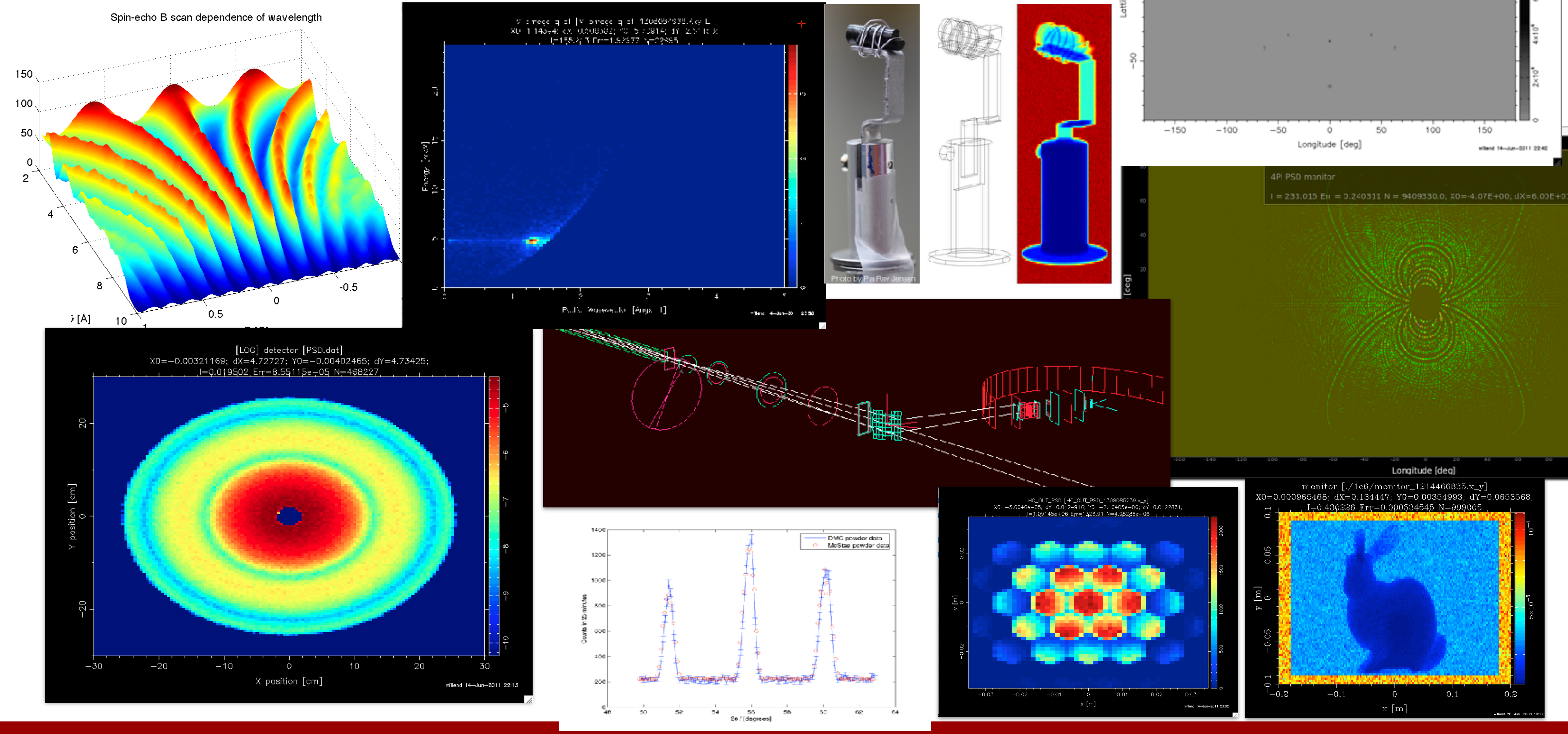
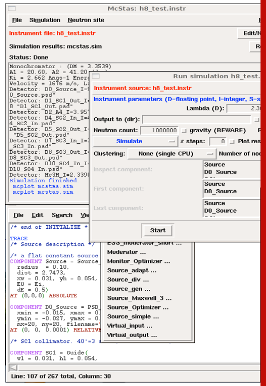


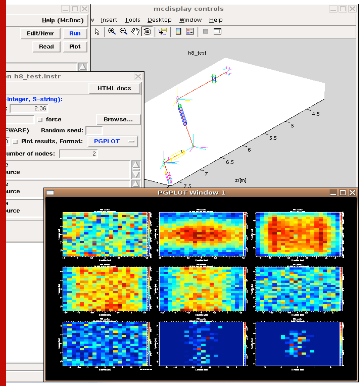

- Well-developed community support
  - –30-40% of existing and new additions are from users
  - –No direct refereeing of the code, but these requirements:
    - –At least one test-instrument
    - –Meaningful documentation headers (in-code docs)
  - –Contributions go in dedicated contrib/ section of library

# Example suite: ~252 instruments







# THIS IS NOT THE END

## IT'S JUST

# THE BEGINNING