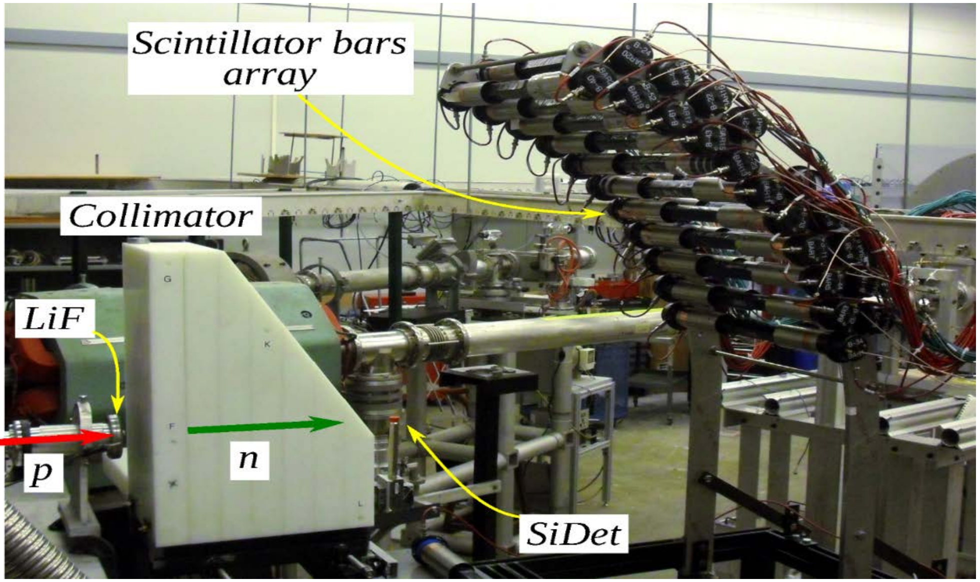

Geometry Survey of the Time-of-Flight Neutron-Elastic Scattering (Antonella) Experiment

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Antonella Experiment

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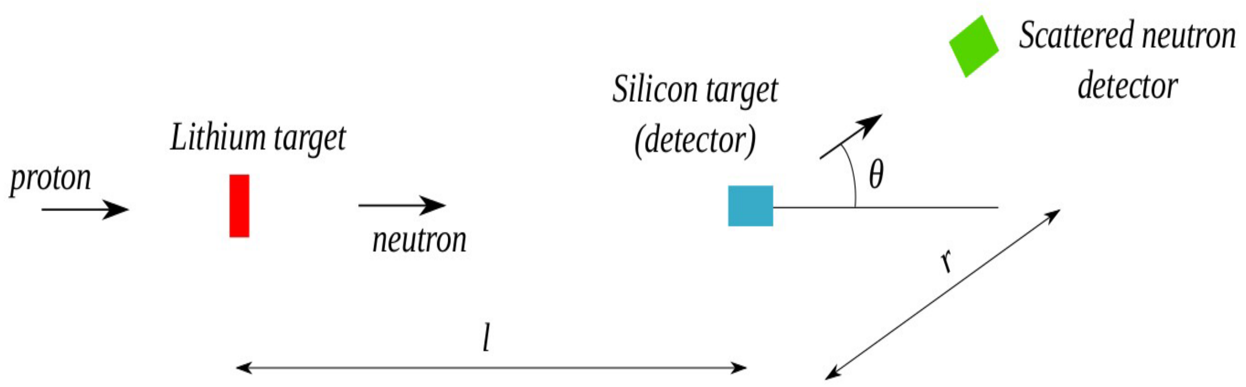
ESRF, Grenoble, France
October 3-7, 2016

The Antonella experiment is

- a measurement of the ionization efficiency of nuclear recoils in silicon at low energies
- a neutron elastic scattering experiment motivated by the search for dark matter particles.
- a calibration experiment for DAMIC (Dark Matter In CCDs) experiment. DAMIC searches for dark matter using Charge Coupled Devices (CCDs)



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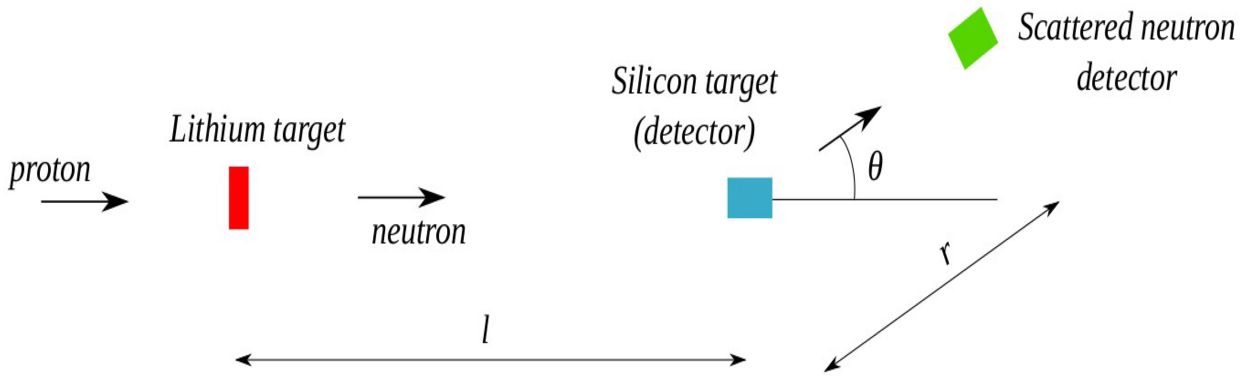
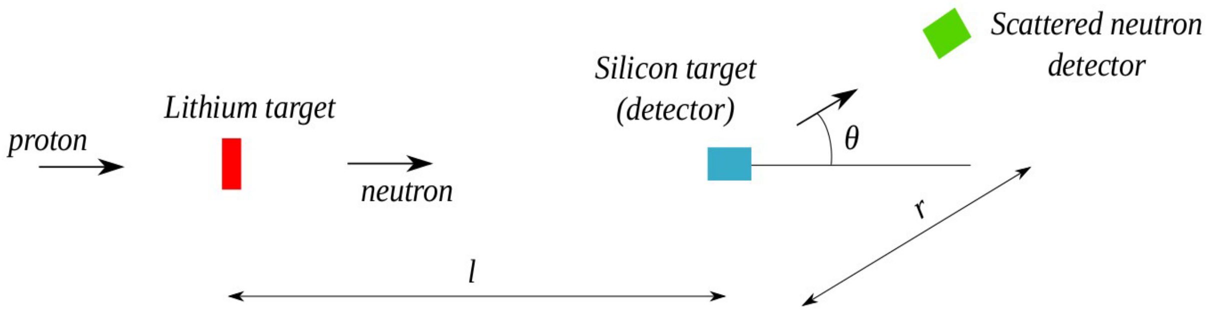


In this experiment

- A proton beam hits a lithium target and neutrons are produced
- The neutron shower passes through a collimator that produces a neutron beam
- The beam illuminates a silicon detector
- With a certain probability, a neutron interacts with a silicon nucleus of the detector producing elastic scattering.
- A neutron-detector array then registers the neutron arrival time and scattering angle to reconstruct the kinematics of the neutron-nucleus interaction with the time-of-flight technique

Neutron elastic scattering: Time-of-Flight technique



The ionization efficiency, 𝓂, of nuclear recoils in silicon at low energies is defined as the ratio of the energy that produces ionization, E_i, with respect to kinetic energy of the nuclear recoil, E_{NR}

$$\varepsilon = \frac{E_i}{E_{NR}}$$

$$E_{NR} = E_n \frac{2}{(A+1)^2}\left[A + \sin^2\theta - \cos\theta\sqrt{A^2 - \sin^2\theta}\right]$$

- □ is the scattering angle with respect to the beam direction,
- A is the atomic number of the silicon nucleus
- E_n is the energy of incoming neutron.

$$E_n = \frac{m_n}{2(\Delta t)^2}\left[l + r\,\frac{(A+1)}{\cos\theta \, + \, \sqrt{A^2 - \sin^2\theta}}\right]^2$$

- Δt is the total time-of-flight of the neutron from the neutron production target to the neutron detector
- m_n is the mass of the neutron
- l is the geometrical distance from the neutron production target to the Silicon Detector (SiDet)
- r is the distance from the SiDet to the neutron detector

Neutron Elastic Scattering: Time-of-Flight Technique

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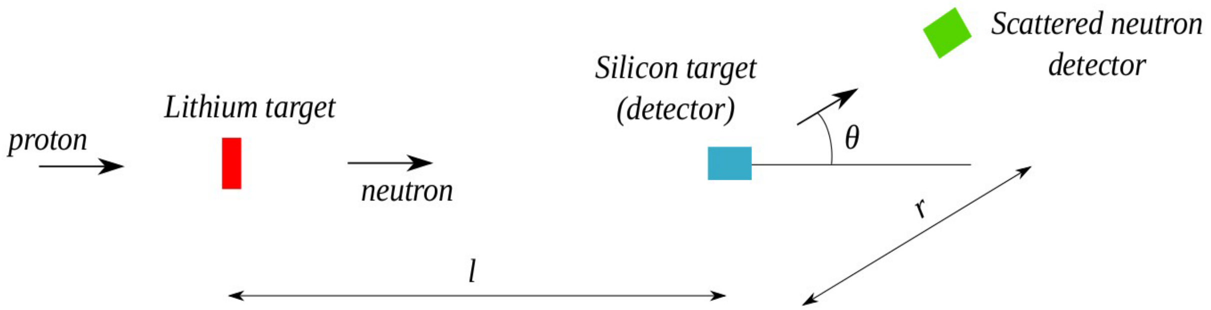

Physics Goal of Antonella Experiment:

1. Measure neutron energy, $E_{n,}$ by time-of-flight
2. Detect a scattered neutrons in a neutron detector
3. Measure charge produced by ionization
4. Calculate the nuclear recoil energy, E_{NR}, with kinematics
5. Determine the ionization efficiency, $\mathcal{M}$

$$\varepsilon = \frac{E_i}{E_{NR}}$$

$$E_{NR} = E_n \frac{2}{(A+1)^2}\left[A + \sin^2\theta - \cos\theta\sqrt{A^2 - \sin^2\theta}\right]$$

$$E_n = \frac{m_n}{2(\Delta t)^2}\left[l + r\,\frac{(A+1)}{\cos\theta + \sqrt{A^2 - \sin^2\theta}}\right]^2$$

Geometry of Antonella Experiment

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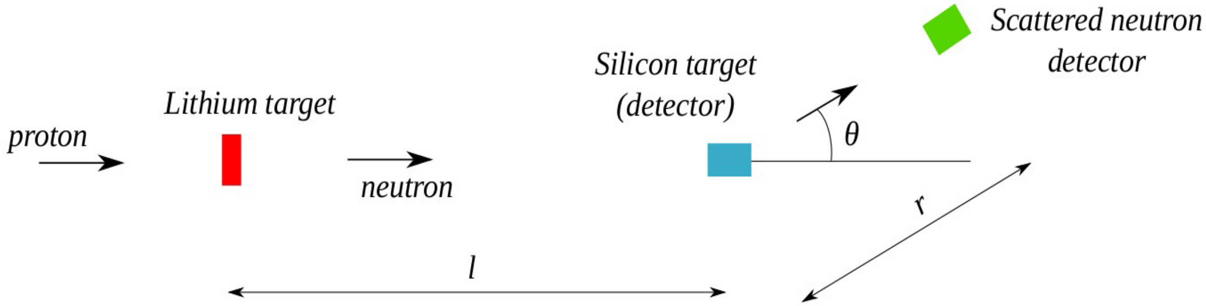


Critical to Antonella Experiment:

1. Geometry of the experiment (***l*, *r*, ❑**) must be determined
2. All components must be aligned to the neutron beam

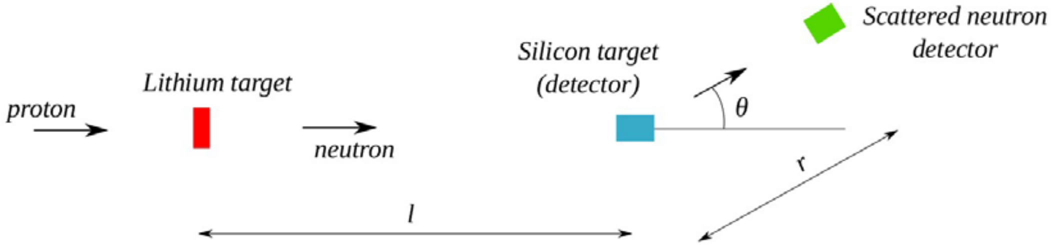
$$\varepsilon = \frac{E_i}{E_{NR}}$$

$$E_{NR} = E_n \frac{2}{(A+1)^2}\left[A + \sin^2\theta - \cos\theta\sqrt{A^2 - \sin^2\theta}\right]$$

$$E_n = \frac{m_n}{2(\Delta t)^2}\left[l + r\,\frac{(A+1)}{\cos\theta + \sqrt{A^2 - \sin^2\theta}}\right]^2$$

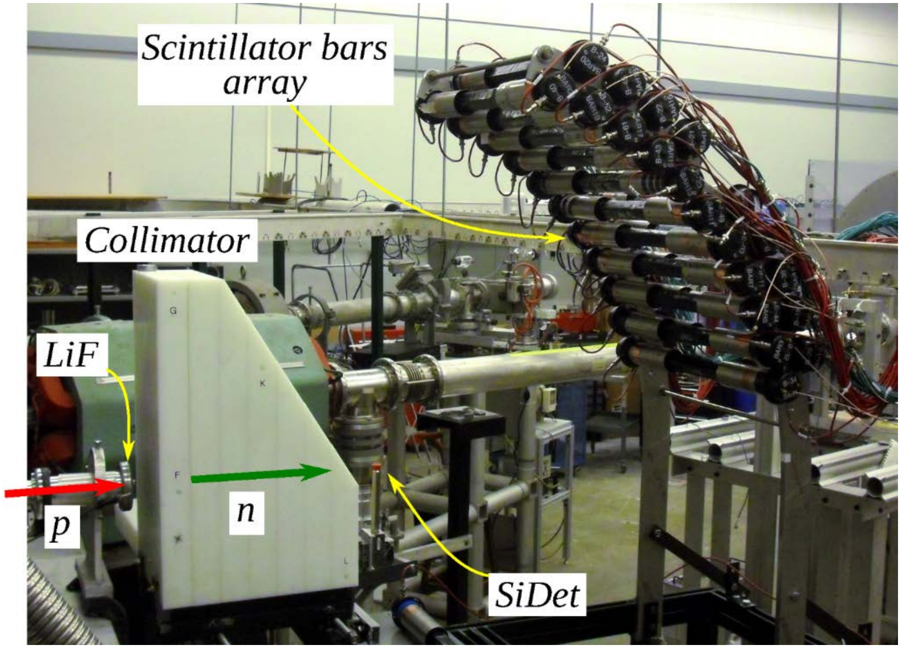
Antonella Experiment at University of Notre Dame (USA)

Antonella experiment was carried out at the FN Tandem Van de Graaff accelerator of the Institute for Structure and Nuclear Astrophysics (ISNAP), University of Notre Dame, Indiana, USA



In this experiment

- A 2.326 MeV **proton** beam hits a lithium target **LiF** and **neutrons** are produced
- The neutron shower passes through a **collimator** that produces a neutron beam.
- The beam illuminates a silicon detector, **SiDet**
- With a certain probability, a neutron interacts with a silicon nucleus of the detector producing elastic scattering.
- A **neutron-detector** array then registers the neutron arrival time and scattering angle to reconstruct the kinematics of the neutron-nucleus interaction with the time-of-flight technique. The **Neutron detector** is an array of **21 Scintillator bars**



Geometry Survey of Antonella Experiment

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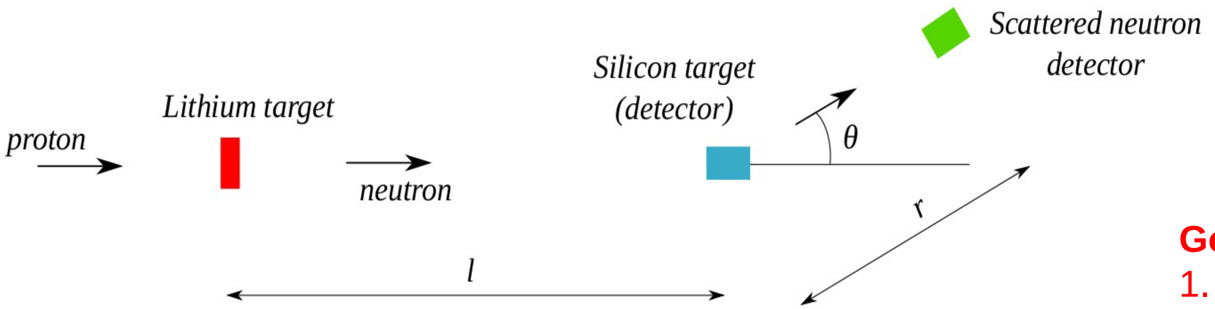
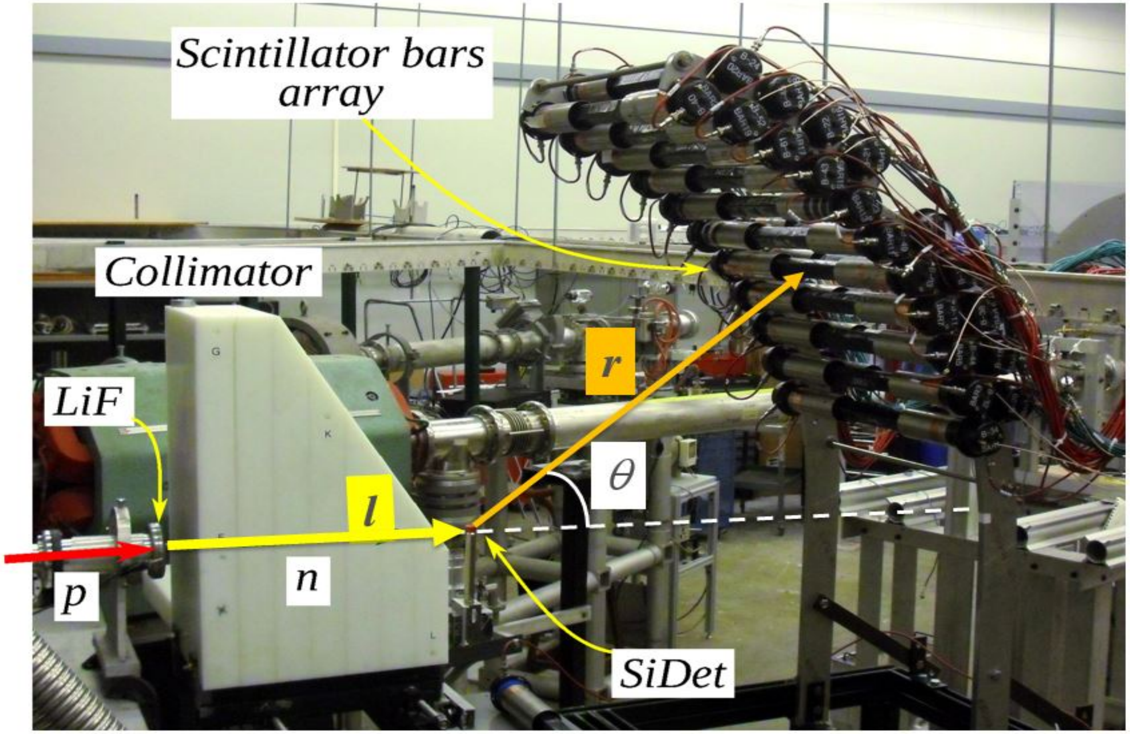


Goal:

1. Determine (***l, r, ❏***)
2. Align all components to the neutron beam



Antonella experiment
University of Notre Dame

Old Survey Methodology

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BEFORE AMD

The experiment was going to use this old telescope to align beam at University of Notre Dame, USA

LATER

The experiment physicist contacted AMD and asked for help to survey the geometric parameters (***l, r,*** □)

Survey Methodology

API Radian
Laser Tracker

SMR

API I-360 Probe
Wireless

- ❑ All Survey for Antonella experiment is done with:

- API Radian™ Laser Tracker. Instrument accuracy is 10 µm
- API I-360™ Probe Wireless. Instrument accuracies for 3D points for up to 7 m distance from the Laser Tracker are 100 µm for horizontal probe position and 125 µm for vertical probe position
- Software: NRK Spatial Analyzer™

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Proton - Lithium Target (LiF)

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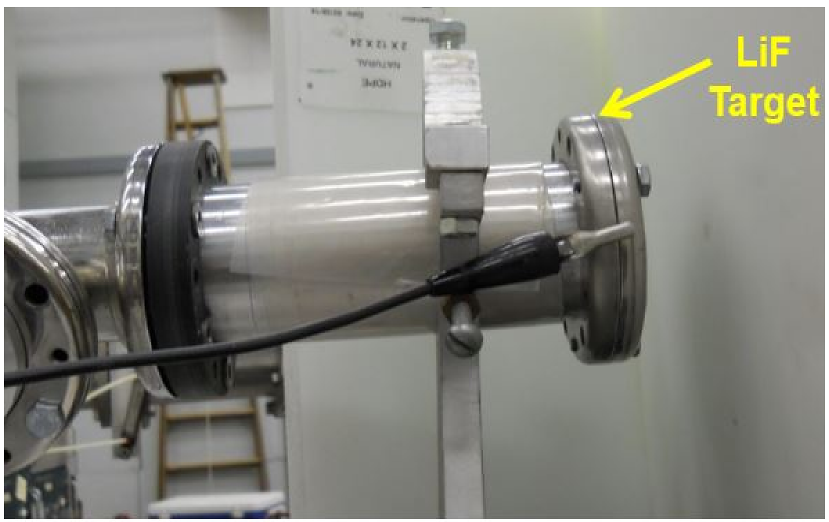

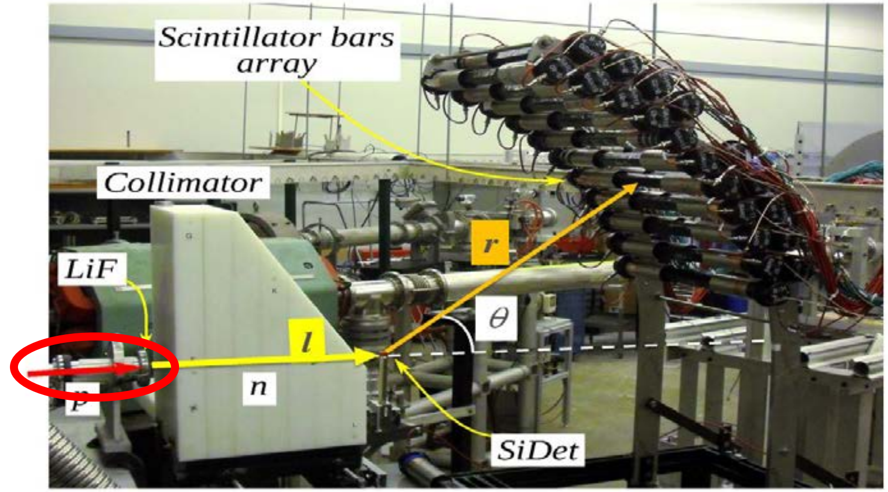

- Proton beam defined by two Flanges
  Cylinder fits made to measurements,
  center of cylinder defines the proton beamline

- Location of LiF Target is center of circle
  fit made to the Flange measurements

Upstream Flange CIRCardinal Points				
Point Name	X	Y	Z	Radius
	mm	mm	mm	
Center	0.04	-380.61	-0.53	47.65
Upstream Beampipe CYL Cardinal Points				
Point Name	X	Y	Z	Diameter
	mm	mm	mm	mm
Begin	0.62	-259.96	0.11	
Center	0.33	-303.85	0.19	61.24
End	0.04	-347.74	0.27	
LiF - Downstream Flange CIR Cardinal Points				
Point Name	X	Y	Z	Radius
	mm	mm	mm	mm
Center	-0.85	-235.13	0.76	47.61

Collimator

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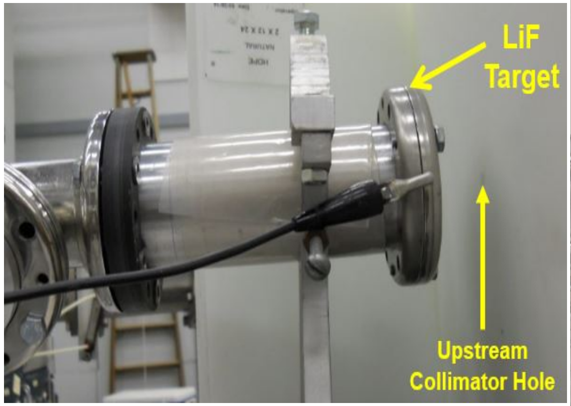

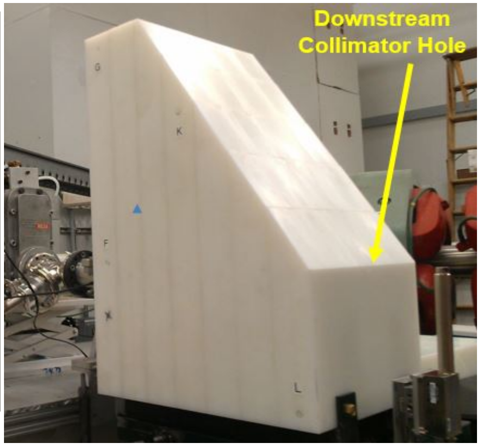

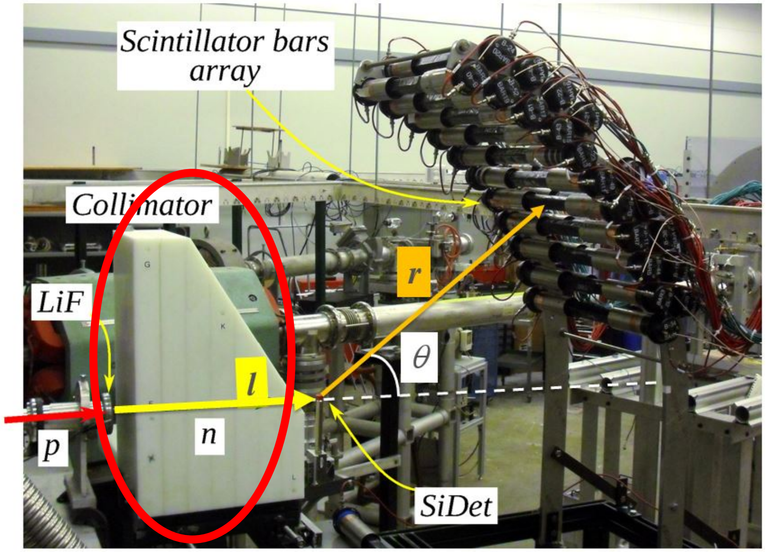

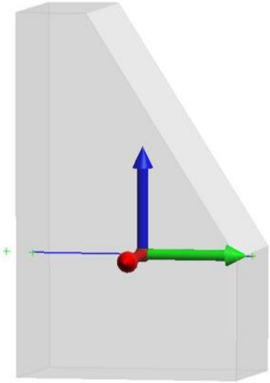

Collimator Frame			
Point	X	Y	Z
	mm	mm	mm
COLL_HOLE_UP	0.00	-188.86	0.00
COLL_HOLE_CT	0.00	0.00	0.00
COLL_HOLE_DN	0.00	188.86	0.00

- Center collimator holes measured as circles
- Neutron beamline is defined by the centers of upstream and downstream holes of the collimator
- All component are aligned to this beamline
- Origin of Antonella coordinate system is at the mid-point between the two holes

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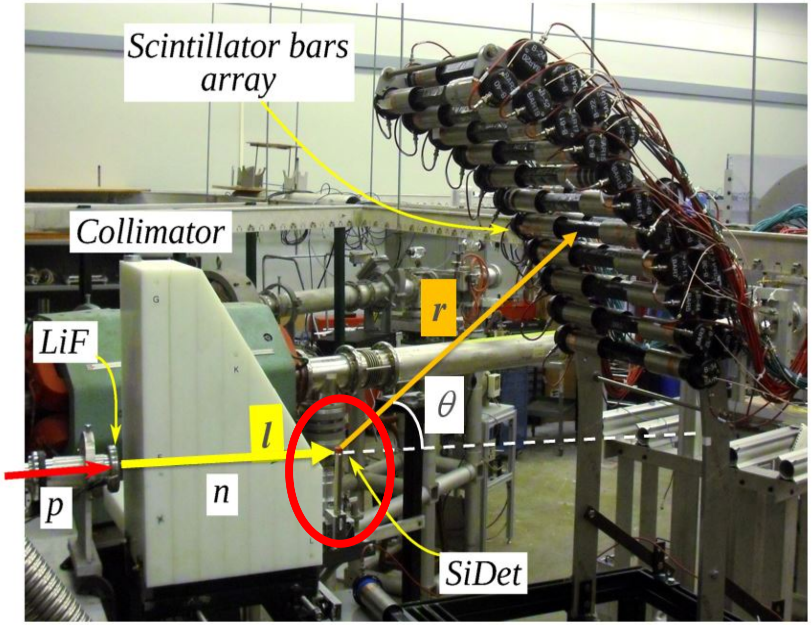
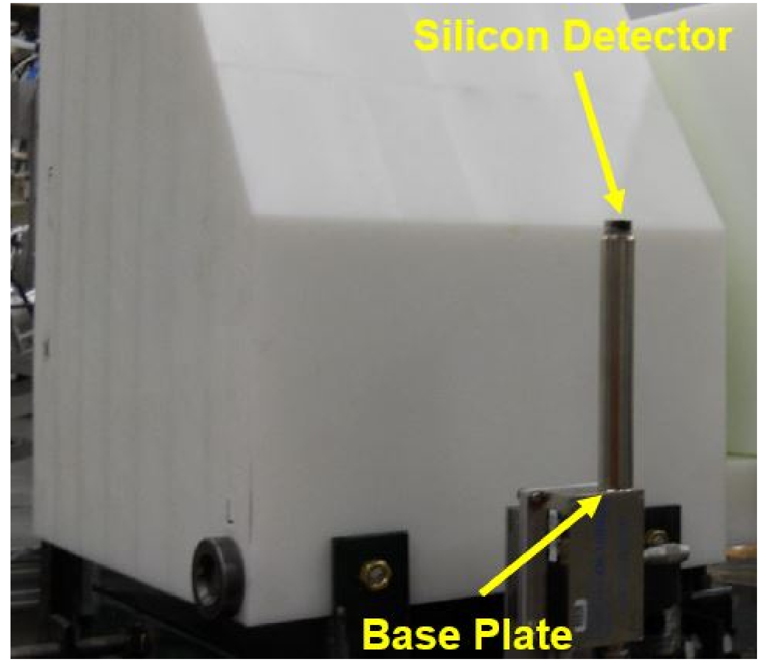
Silicon Detector (SiDet)





- Location SiDet is center of circle fit made to the top of SiDet measurements
- Center of SiDet is aligned to the neutron beamline
- Geometric Parameter, *l* = 516.48 mm

LiF - Downstream Flange to SiDet Detector Center				
	X	Y	Z	Mag
	(mm)	(mm)	(mm)	(mm)
LiF to SiDet Detector Center	-0.85	-235.13	0.76	
SDD_CT - SiDet Detector Center	-0.15	281.34	0.54	
Delta	0.71	516.47	-0.22	**516.48**
COLL_HOLE_CT to SiDet Detector Center				
	X	Y	Z	Mag
	(mm)	(mm)	(mm)	(mm)
COLL_HOLE_CT	0.00	0.00	0.00	
SDD_CT - SiDet Detector Center	-0.15	281.34	0.54	
Delta	-0.15	281.34	0.54	**281.34**
COLL_HOLE_DN to SiDet Detector Center				
	X	Y	Z	Mag
	(mm)	(mm)	(mm)	(mm)
COLL_HOLE_DN	0.00	188.86	0.00	
SDD_CT - SiDet Detector Center	-0.15	281.34	0.54	
Delta	-0.15	92.49	0.54	**92.49**

Geometric Parameter, *l*

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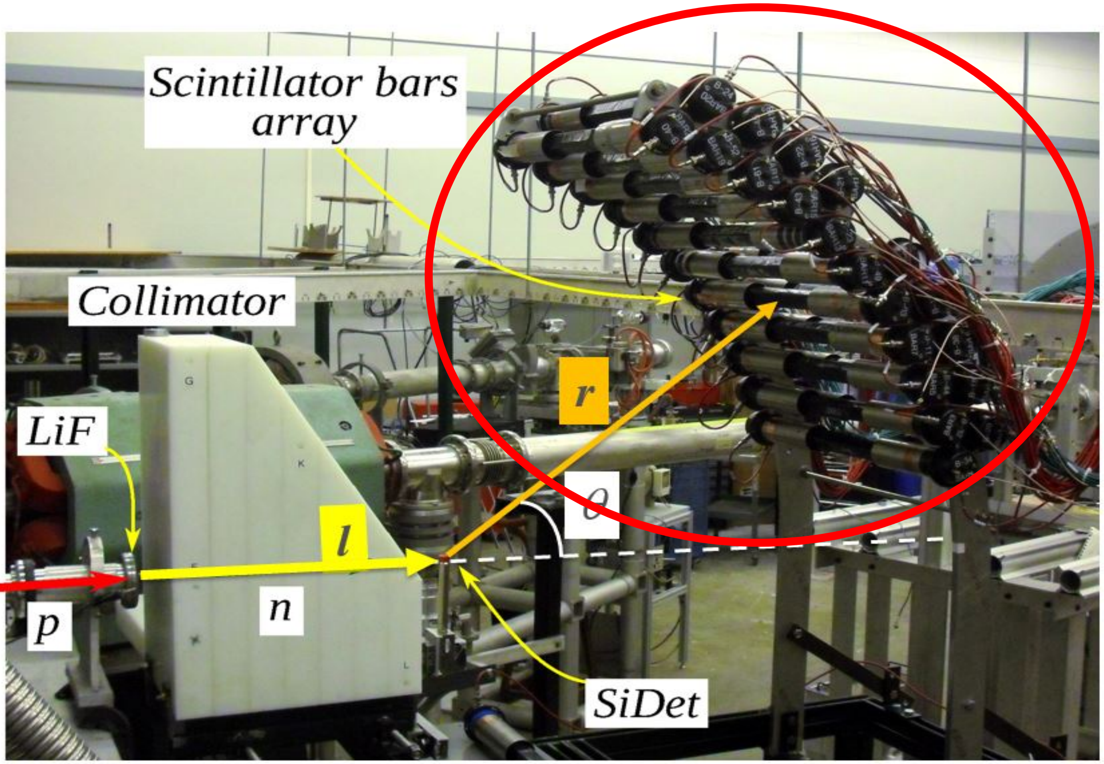
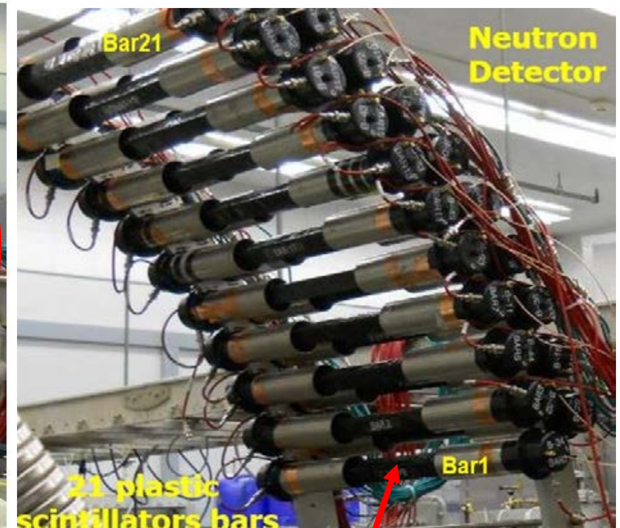
Scattered Neutron Detector





- A scattered neutron detector is a single scintillator bar.
- The Antonella neutron detector is an array of 21 plastic scintillators bars.

Each bar is 30 mm x 30 mm of cross section and 250 mm in length coupled to two photomultiplier tubes (PMTs)

Survey neutron detector to determine (*r*, *❑*)

Scintillator Bar Measurements

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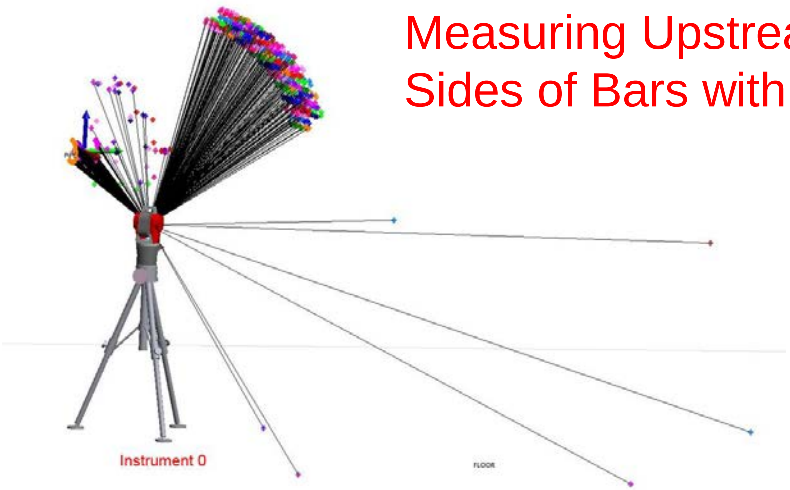
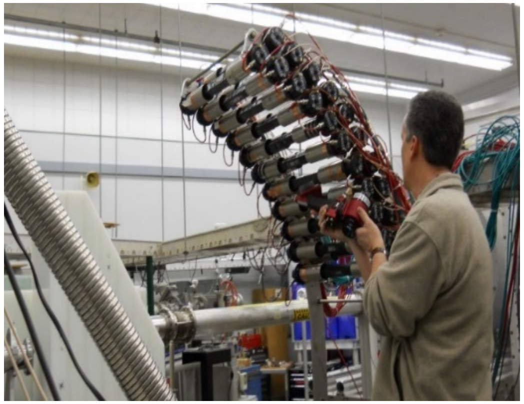
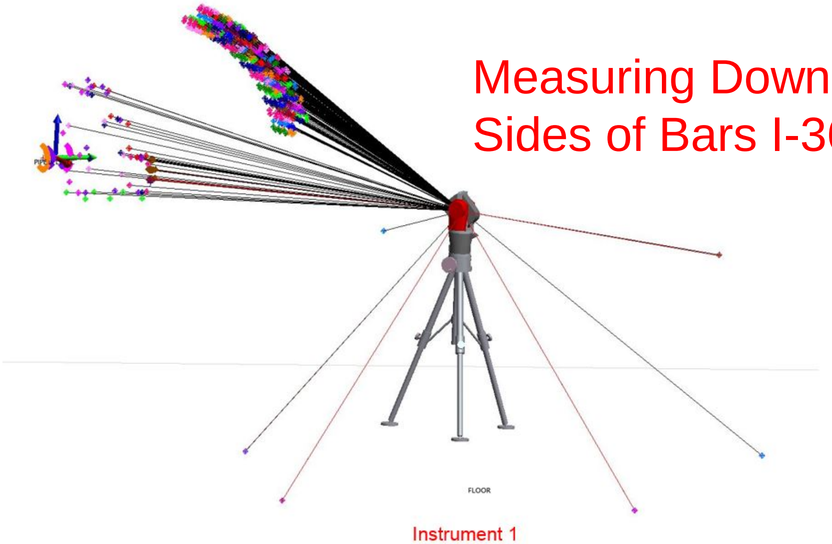
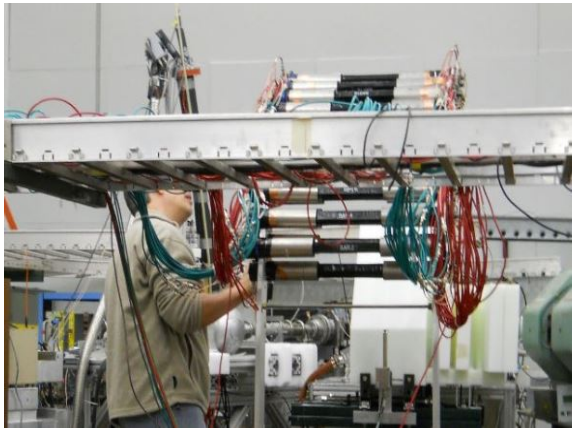


Measuring Upstream
Sides of Bars with I-360 Probe

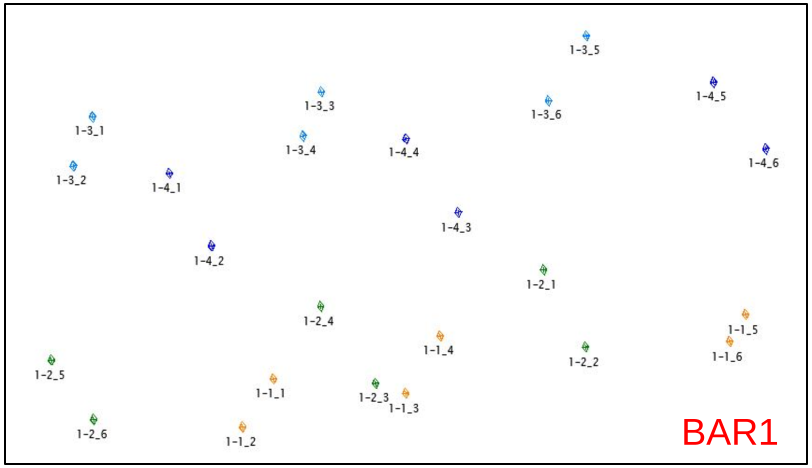


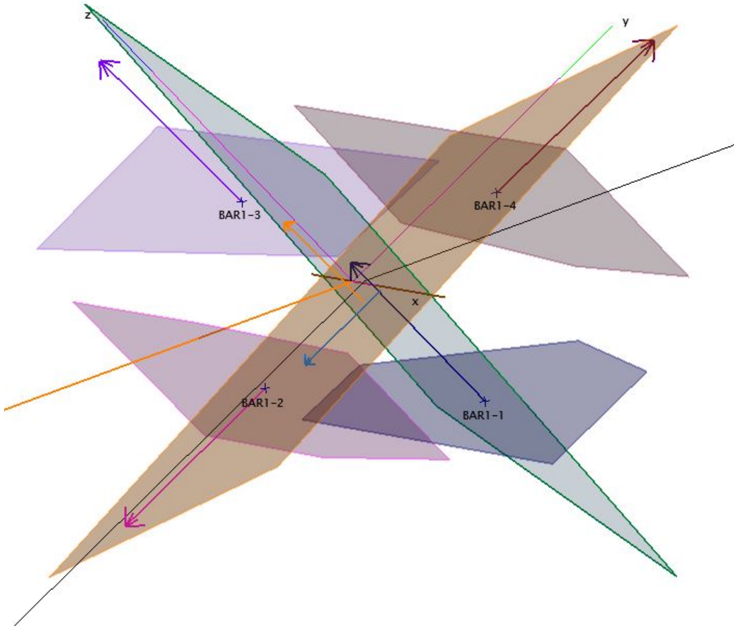


Measuring Downstream
Sides of Bars I-360 Probe



Geometric Parameters, *r, and θ*





- Six points were measured with the I-360 probe on all the four sides of each scintillator bar. Total 504 points were measured for 21 bars
- A plane was fitted to the six points on each side of the bar, e.g., BAR1_1, BAR1_2, BAR1_3, and BAR1_4 planes for the first bar – BAR1
- A mid-plane was constructed from BAR1_1 and BAR1_3 planes and another mid-plane from BAR1_2 and BAR1_4 planes
- A line, Line-BAR1, was constructed by intersecting the two mid-planes using the plane-plane intersection function of the Spatial AnalyzerTM software. This line defined the geometric center of bar BAR1
- A point BAR1, was constructed on this line by intersecting the X = 0, YZ plane along the beamline with Line-BAR1. The geometric parameters, *(r, θ)* were computed from the coordinates of center of SiDet and the coordinates of point BAR1
- Similar steps were done for bars BAR2 through BAR21

Geometric Parameters, *r and θ*

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Bar	*r*	*θ*
	mm	deg°
Bar1	812.93	12.5616
Bar2	889.29	15.7350
Bar3	810.09	18.3704
Bar4	887.08	21.9356
Bar5	807.91	24.5887
Bar6	880.05	28.0100
Bar7	805.72	31.0376
Bar8	881.35	34.0061
Bar9	805.80	36.8804
Bar10	878.83	40.0771
Bar11	800.00	43.0287
Bar12	878.41	46.2167
Bar13	801.07	49.3142
Bar14	878.73	52.4377
Bar15	802.72	55.4187
Bar16	880.03	58.4409
Bar17	802.42	61.6556
Bar18	880.70	64.4979
Bar19	803.16	67.6690
Bar20	886.13	70.6591
Bar21	805.54	73.9442

Geometric Parameters ***r*** and ***θ*** for all 21 bars along with the value of ***l* = 516.48 mm** were sent to the experiment physicist to be used for analysis

Conclusion

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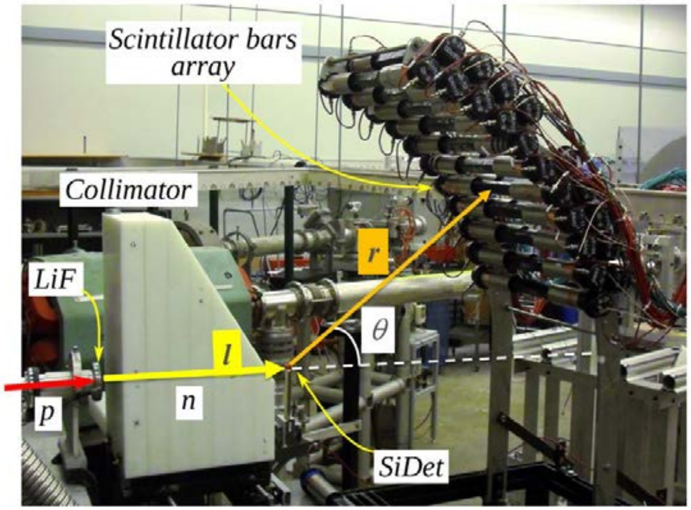

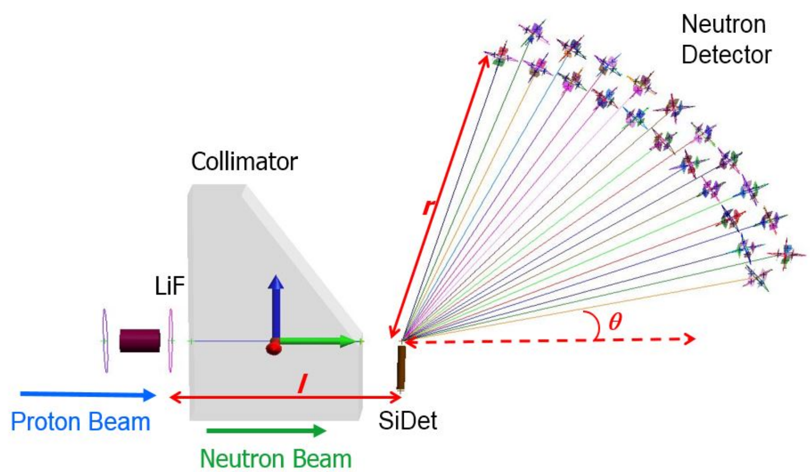

- The geometric parameters of the Antonella experiment (*l, r, θ*) were surveyed at the University of Notre Dame, Indiana
- The high accuracy of the survey was critical to reducing the systematic uncertainties of the ionization efficiency measurement
- The fact that these uncertainties were minimized made the contribution of the Antonella experiment relevant and competitive

Acknowledgment

❑ We would like to thank

- Chuck Wilson and Mike O'Boyle of the Alignment and Metrology Department

Questions?

Preguntas?

Fragen?

質問？

题？