Alternatives to ^{3}He Detectors for Neutron Scattering Instruments

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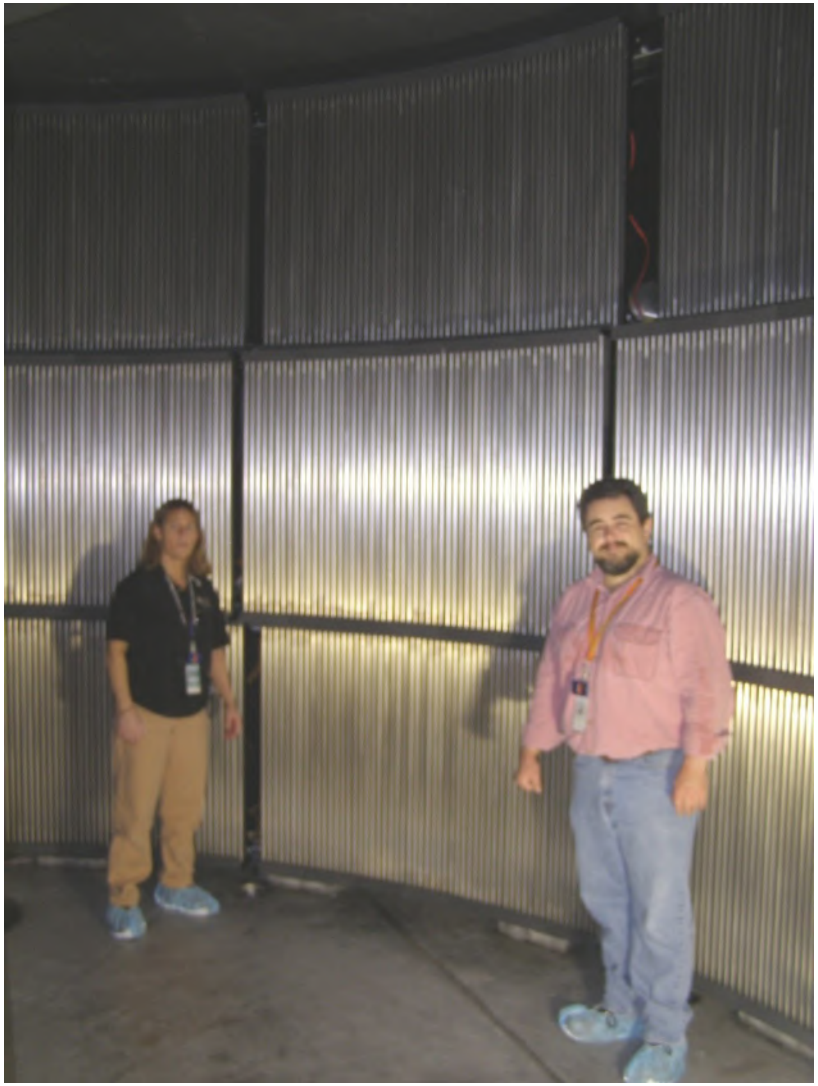
6 April, 2010

AAAS Workshop Breakout Session

^{3}He Arrays

- **Approximately 75% of the detectors for neutron scattering use ^{3}He**
- **These detectors are efficient, stable, low noise, have excellent gamma discrimination, and good timing**
- **Unfortunately they are a thing of the past**

- **ARCS Instrument at SNS**
- **920 LPSD tubes**
- **Just completed a series of experiments studying iron based superconductors**



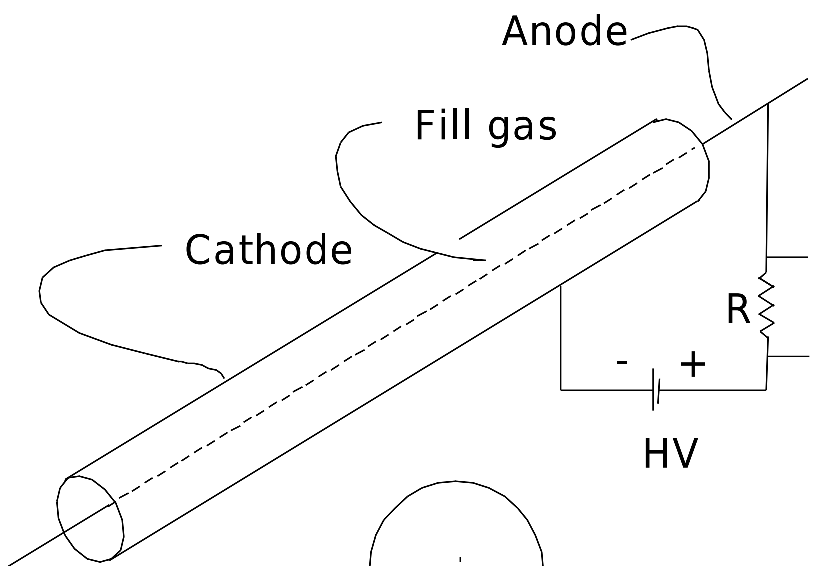
ARCS detectors
In vacuum tank

Gas Detectors

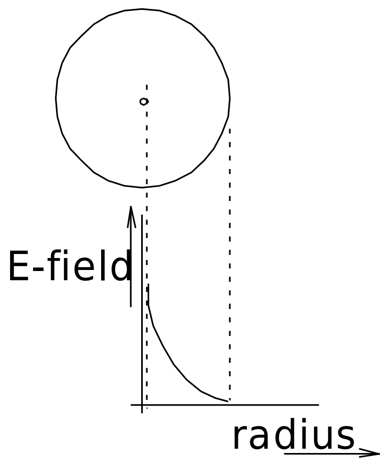
$$n + {}^{3}He \rightarrow {}^{3}H + {}^{1}H + 0.76\,MeV$$

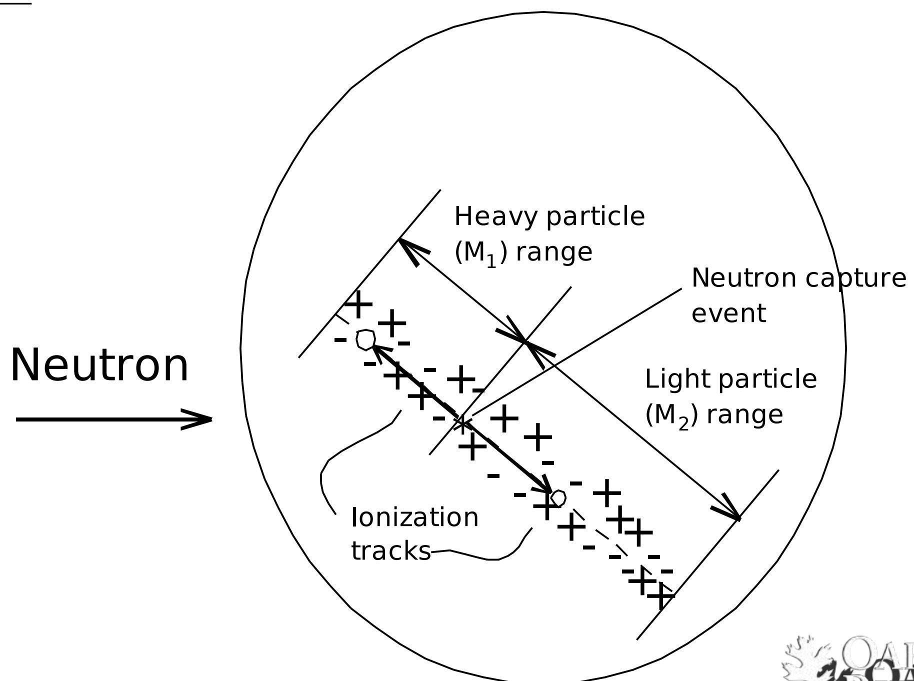
Gas Proportional Counter

$$\sigma = 5333 \frac{\lambda}{18} \text{ barns}$$



~25,000 ions and electrons ($\sim 4 \times 10^{-15}$ coulomb) produced per neutron





Alternative Isotopes

- **Neutrons interact via the strong force and isotopes with high neutron capture cross sections are required for efficient detection systems**
- **The daughter products from the captures must include energetic charged particles that will generate detectable signals**
- **Neutrons of a broad energy range are used and cross sections should be well behaved with respect to energy**
- **Isotopes should be plentiful**

- **For neutron scattering instruments the kinetic energy of the neutron is too small for proton recoil**

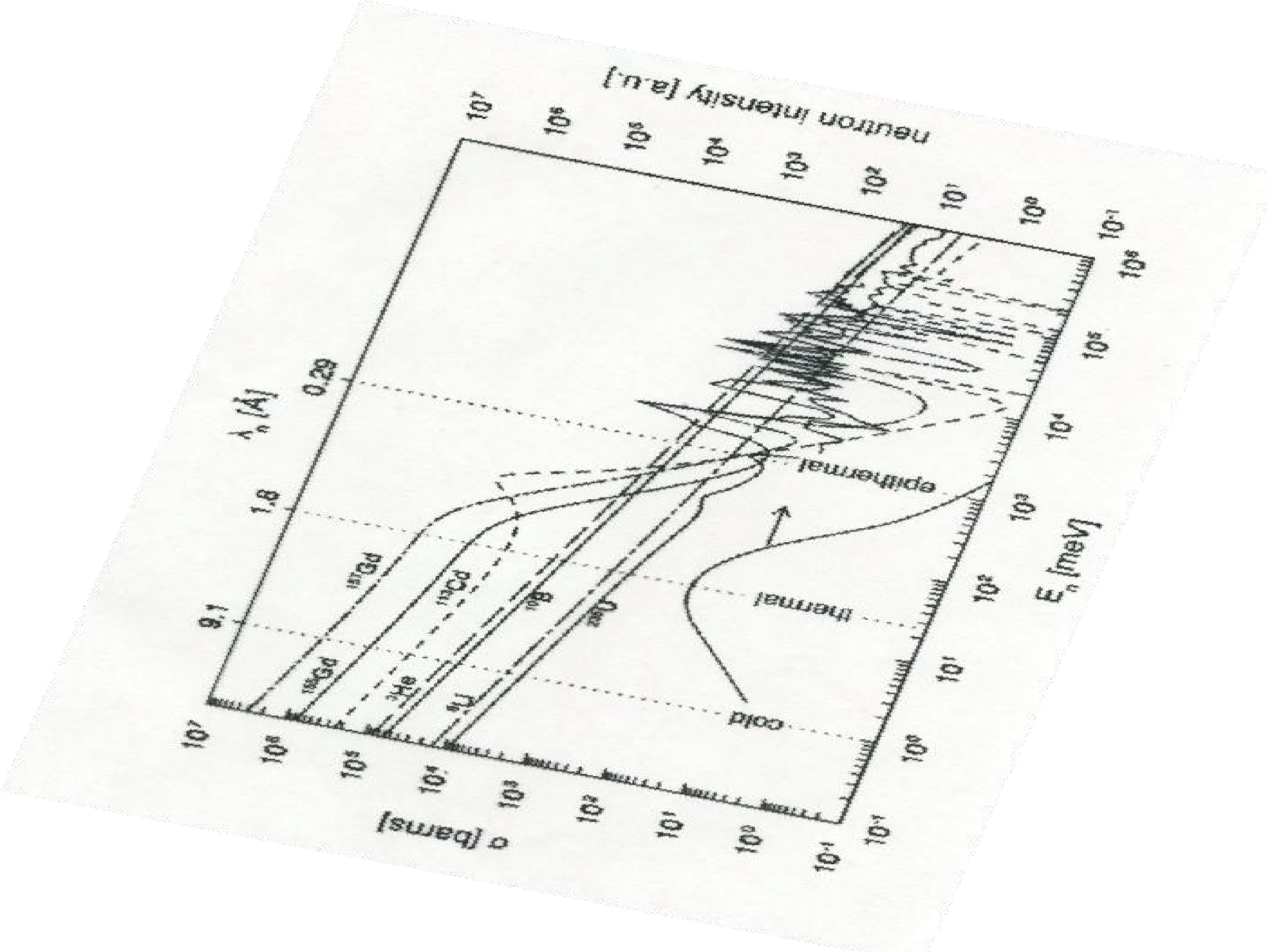
Neutron Converters

Isotope	State	Reaction	Cross Section (b)	Absorb. Length	Product Energies (keV)	Product Range
^{3}He	gas	$^{3}He(n,p)t$	5333	7.59 bar-cm	P:573, t:191	R_p = 0.43 bar-cm CF_4
^{6}Li	solid	$^{6}Li(n,\alpha)t$	940	230µm	T:2727, α:2055	R_t = 130 µm
^{10}B	solid	$^{10}B(n,\alpha)^{7}Li$	3836	19.9µm	α:1472, ^{7}Li:840	R_α = 3.14 µm
$^{10}BF_3$	gas	$^{10}B(n,\alpha)^{7}Li$	3836	9.82 bar-cm	α:1472, ^{7}Li:840	R_α = 0.42 bar-cm
^{nat}Gd	solid	$^{nat}Gd(n,\gamma)$	49122	6.72µm	Ce:29-182 (86.5%)	$\Lambda_{œ}$ =12.3 µm

25meV Neutron

Data from T. Wilpert, (HZB)

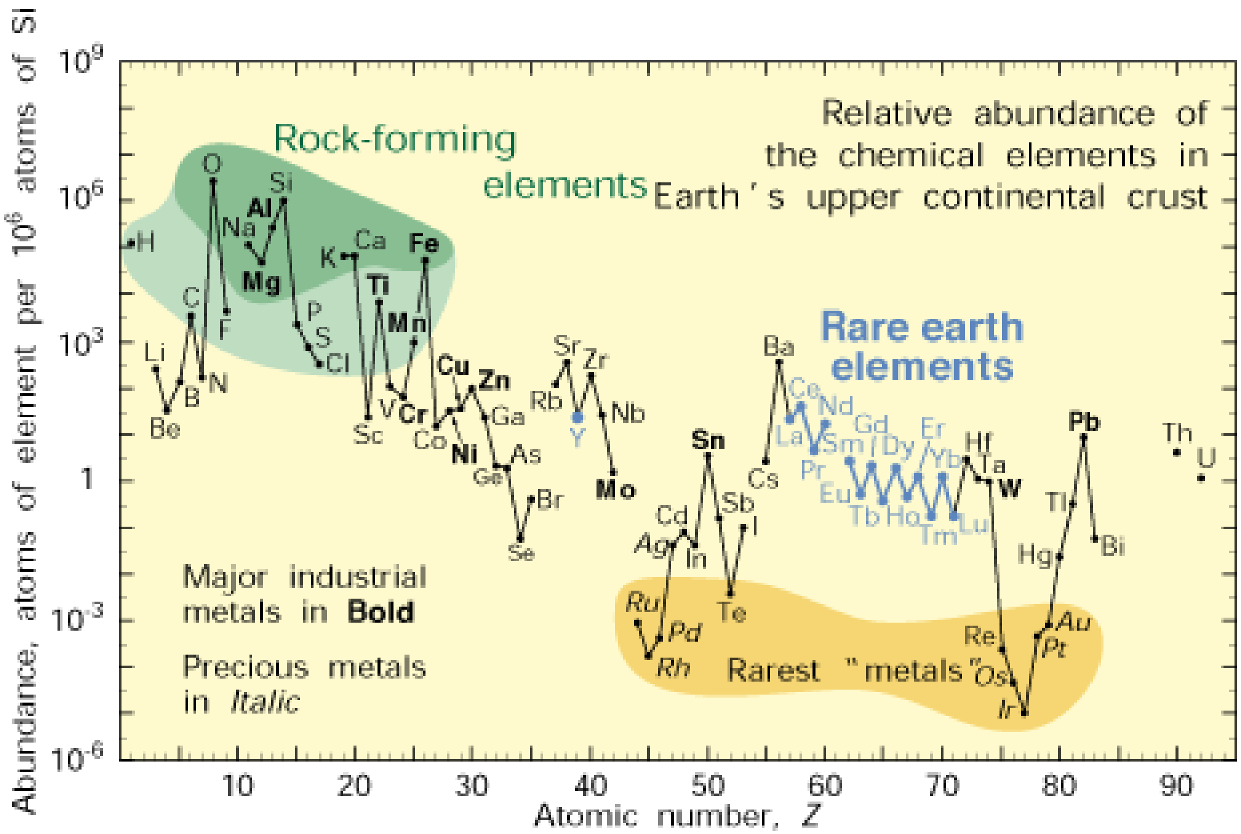
Cross Sections



G. Smith, (BNL)

Abundance Comparison

- ^{3}He from tritium decay
- Lithium has an average abundance and approximately 5% is ^{6}Li
- Boron has an average abundance and is about 20% ^{10}B



http://pubs.usgs.gov/fs/2002/fs087-02/

Requirements for Neutron Detection for Homeland Security – R. Kouzes

- **Neutron alarms initiate separate standard operating procedure**
- **Neutron background from cosmic ray produced secondaries at a very low rate (1000 times smaller than gamma rays)**
- **Fast (~1 MeV) and slow neutron detection required with flat response**
- **Meet or exceed all ANSI N42.35/N42.38 requirements**

- **Absolute efficiency: ϵ_{abs} = 0.11% or 2.5 cps/ng of ^{252}Cf (at 2 m in a specified configuration)**
- **Minimum gamma ray discrimination (ϵ_{int}) of 10^{-6} or better**
- **Ratio with gamma exposure of 10 mR/h: $0.9 < \epsilon_{abs\gamma}/\epsilon_{abs} < 1.1$**

Requirements for Alternative Neutron Detection for Homeland Security

- **Readily available commercially within <u>4 months</u>**
- **Physically fit in the volume currently occupied by the neutron detection assembly in existing RPM systems (11.4 cm x 30.5 cm x 218.4 cm)**
- **Thermal and fast neutron detection**
- **Rugged, reliable, and accurate**
- **Non-responsive to gamma rays**
- **Safe**
- **Inexpensive**

Requirements for Neutron Scattering

Table 3. Instrument requirements

Instrument	Number of pixels	Pixel area (cm^2)	Maximum neutron energy (eV)	Neutron capture efficiency %	Gamma efficiency	Time resolution (μs)	Peak pixel count rate ($n.s^{-1}$)	Detector count rate ($n.s^{-1}$)	Data transfer rate (Mb/s)
Powder Diffractometer	40,000	2.4	0.33	50	10^{-6}	1	100	3.5×10^6	28
Disordered Materials Diffractometer	150,000	0.25	50	20	10^{-6}	1	300	4.2×10^7	340
High-Pressure Diffractometer	100,000	0.02	0.5	50	10^{-7}	1	1×10^4	3.0×10^5	2.4
Engineering Diffractometer	80,000	1.25	0.15	50	10^{-6}	1	2×10^5	2.4×10^6	20
Single-Crystal Diffractometer	5×10^6	0.01	0.35	50	10^{-6}	10	2×10^4	3.0×10^5	2.4
SANS Diffractometer	40,000	0.25	0.08	50	10^{-7}	10	1,500	2.0×10^7	160
Liquids Reflectometer	40,000	0.01	0.02	50	10^{-7}	10	1×10^6	7.0×10^7	560
Magnetism Reflectometer	40,000	0.01	0.03	50	10^{-7}	10	1×10^6	9.0×10^7	720
Backscattering Spectrometer	4,500	1.3	0.01	50	10^{-6}	1	1×10^4	1.3×10^5	1
ARC Spectrometer	70,000	2.5	1.0	50	10^{-7}	1	1×10^6 (Bragg)	5.0×10^5	4
CNC Spectrometer	15,000	6.3	0.05	50	10^{-7}	4	1×10^6 (Bragg)	7.0×10^6	56
HRC Spectrometer	70,000	2.5	1.0	50	10^{-7}	1	1×10^6 (Bragg)	4.0×10^5	3.2

Alternative Detectors for Large Areas

- **Proportional counters**
  - **Li lined (extremely difficult)**
    - **Lithium compounds are reactive**
    - **Relatively low cross section limits efficiency**
    - **Lithium ions can drift in an electric field (battery)**
  - **B lined**
    - **Short range of products limits efficiency**
  - **BF_3 gas**
    - **High bias voltage limits pressure**
    - **Corrosive**
  - **Gd lined (can't meet requirements)**
    - **80 keV mean electron energy causes poor gamma rejection**

Alternative Detectors for Large Areas

- **Scintillation Detectors**
  - **LiFZnS:Ag scintillator with fiber readout**
    - **Slow scintillator > 10 μs**
    - **Opacity of scintillator limits efficiency**
  - **Anger cameras with Li glass (GS20)**
    - **Cost**
    - **Moderate gamma rejection**
  - **B loaded scintillator**
    - **Low light levels**
    - **Can be thin**
  - **Gd loaded scintillator (can't meet requirements)**
    - **Used in imaging**
    - **Insufficient light for single neutron imaging**

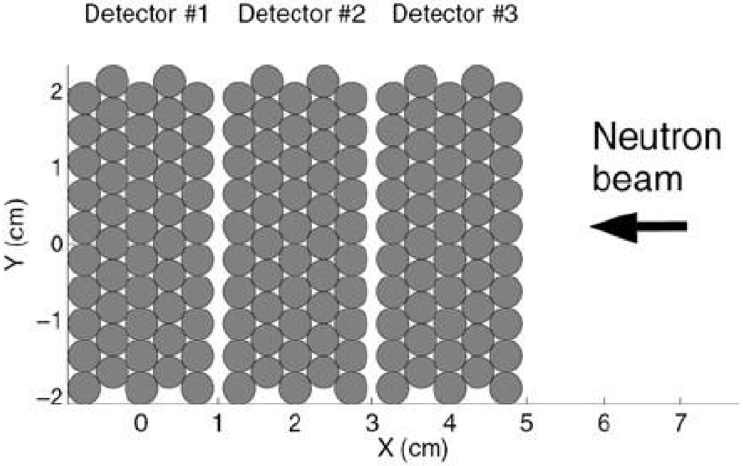
Boron Lined Proportional Counters

- **Commercially available from several vendors**
- **The detector has a thin layer of ^{10}B on the inside wall of the tube**
- **Due to the short range of the daughter products the layer thickness is limited to about 2μm**
- **Uses standard chamber gas such as P10**

Centronics Tube

Boron Lined Proportional Counters

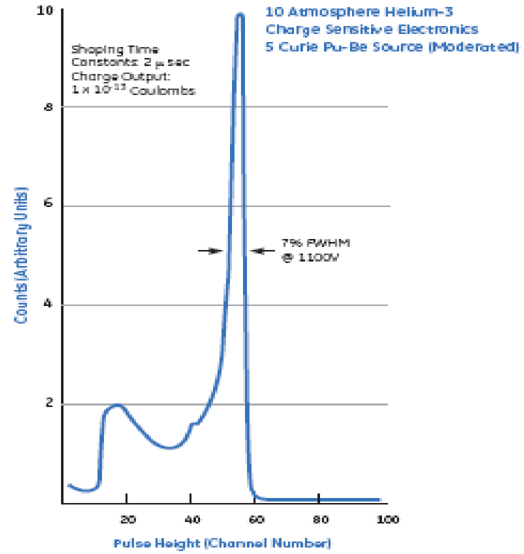
- •Detection efficiency for a thermal neutron from a 2μm thick layer is 2% at best
- •Multiple layers are needed to achieve acceptable efficiencies
- • By using (x,y) readout schemes the capture can be located to a specific tube without requiring a preamp per tube.
- •Space charge saturation is not an issue
- •Multiple walls increase gamma sensitivity
- •Lack of energy resolution peak may limit gamma discrimination



Proportional Technologies

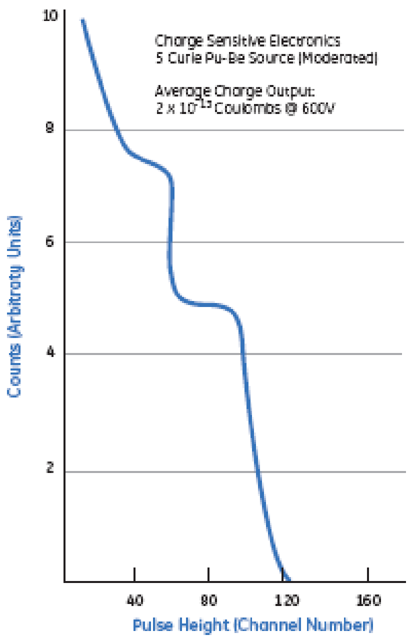
Energy Resolution

- **Detectors need good energy resolution and separation from gamma background to enable gamma discrimination**
- **Gammas generate a low energy background with an exponential tail**
- **^{3}He tubes have excellent gamma discrimination, on the order of 10^{-7}**
- **Boron lined tubes have no peak separation**
- **BF3 tubes have better separation than helium**



^{3}He

Typical Differential Pulse Height Spectrum

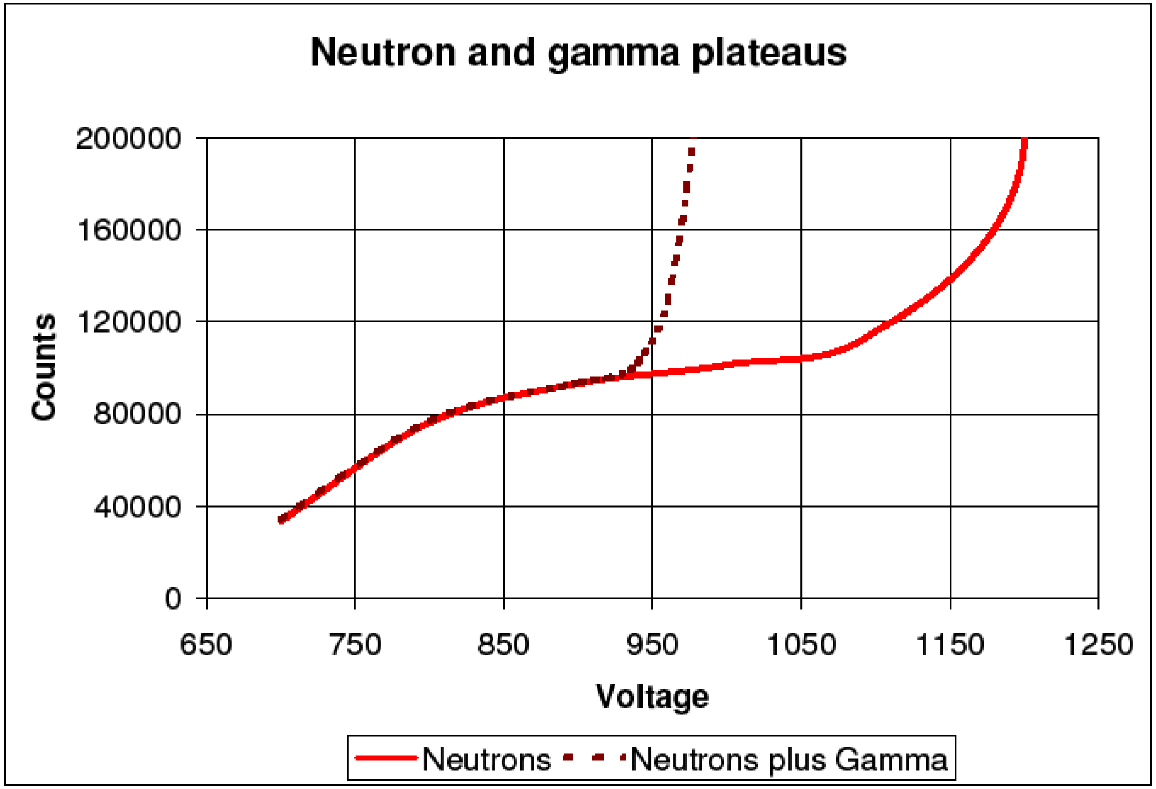


Boron Lined Tube

Images from GE Reuter Stokes

Boron Lined Tube Gamma Discrimination

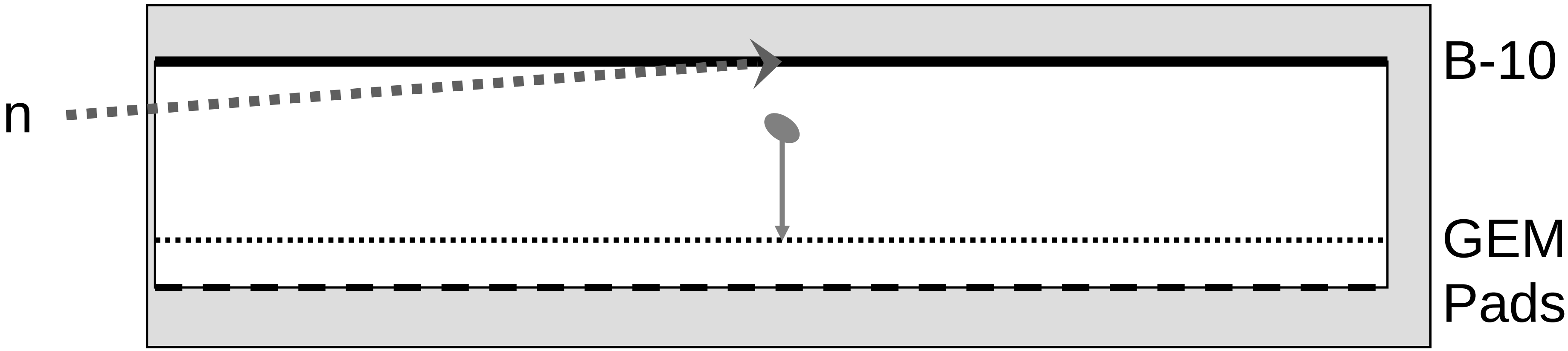
- **Set bias at 900V to minimize gamma events**
- **May not work for neutron scattering where both good position resolution and high rate performance is required**



GE Reuter Stokes

Inclined Boron Detectors

- Counting gas transparent to neutrons
- 10B for absorbing neutrons, which produces:
- $^{10}B + {}^{0}n \rightarrow {}^{7}Li + {}^{4}He + 2.3\ MeV$



- **The resulting ionization is multiplied by the Gas Electron Multiplier (GEM) and induces a signal on the pads**
- **Tile into an array as Venetian blinds or Multi-blades**

BF3 Proportional Counters

- **Q value is 2.3MeV (3x helium) so BF3 has excellent gamma rejection**
- **Cross section is 72% of helium**
- **High voltage bias increases rapidly with pressure**
- **Efficiency is limited by the pressure**

Centronics Tubes

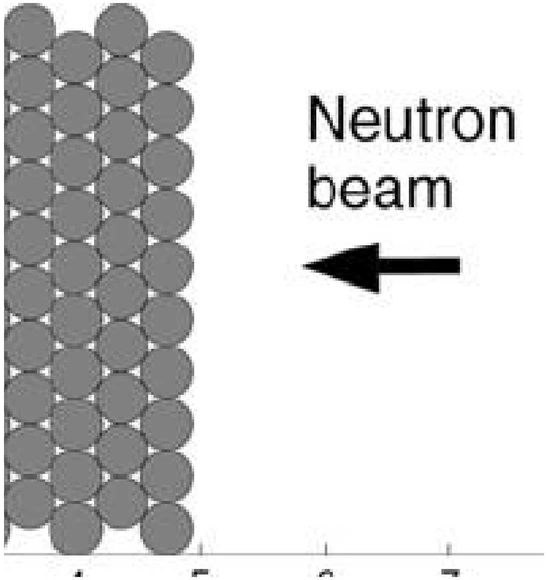
Comparison with ARCS ^{3}He Tube

- **Detectors are 1m long and 25mm diameter, 25meV neutron**
- **Values are from Centronics for BF3 and GE Reuter-Stokes for He**

Detector	Pressure (Pa)	HV Bias (V)	Efficiency (cps/nv)
BF3	27k	1300	12
BF3	53k	1800	23
BF3	93k	2400	39
^{3}He ARCS	1,010k	1850	170

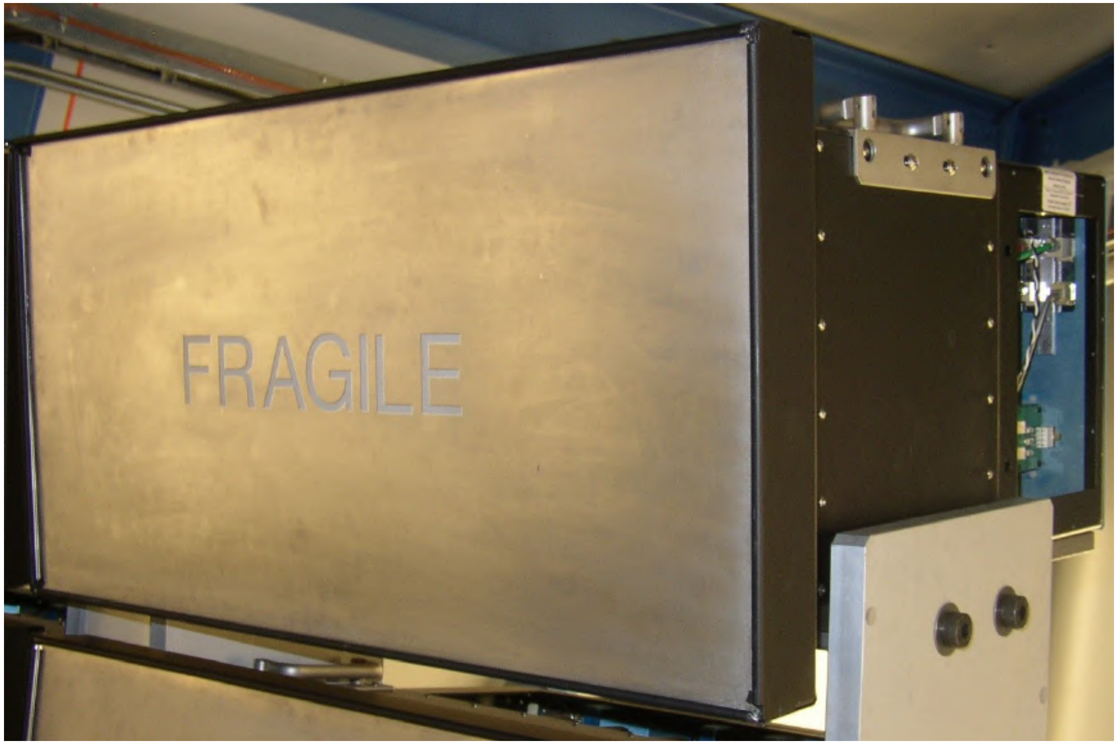
BF3 Detectors

- **Depending wavelength range, reasonable efficiency could be achieved with 2 to 4 rows of tubes**
- **Need to address the corrosive nature of the gas**



Shifting Scintillator Neutron Detector (SSND)

- LiFZnS:Ag scintillator
- Wavelength shifting fiber readout
- Can be clear fiber like ISIS design
- Area: 0.3 m^2
- Pulse shape gamma discrimination
- 0.5 x 5 cm position resolution, needs to be adjusted
- 5 μs time resolution for thermal neutrons



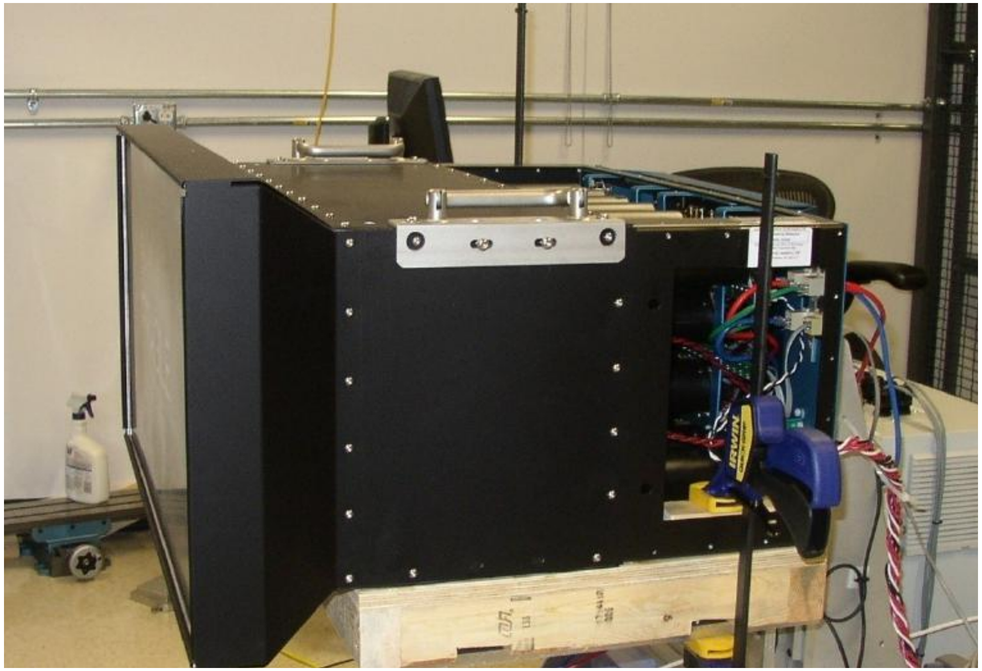
- Count Rate goal: 10^5 n/s
- Capture efficiency: 75% for thermal neutrons

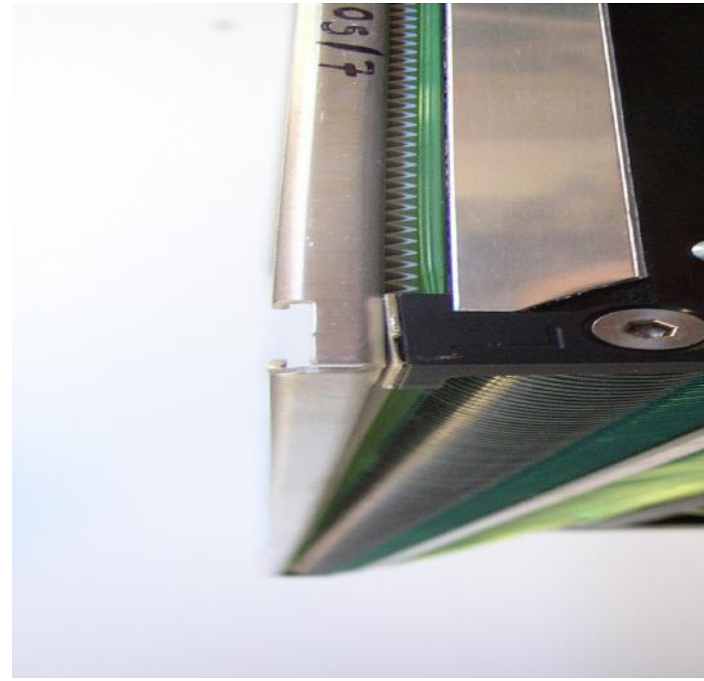
Production Status

- **ORNL has a contract with PartTec LLC. to partner on detector production**
- **30 detectors are at SNS in various stages of production**
- **PartTec is willing to work with other labs to develop these detectors for other uses**

8 Detector array in POWGEN Instrument at SNS

Detector Details

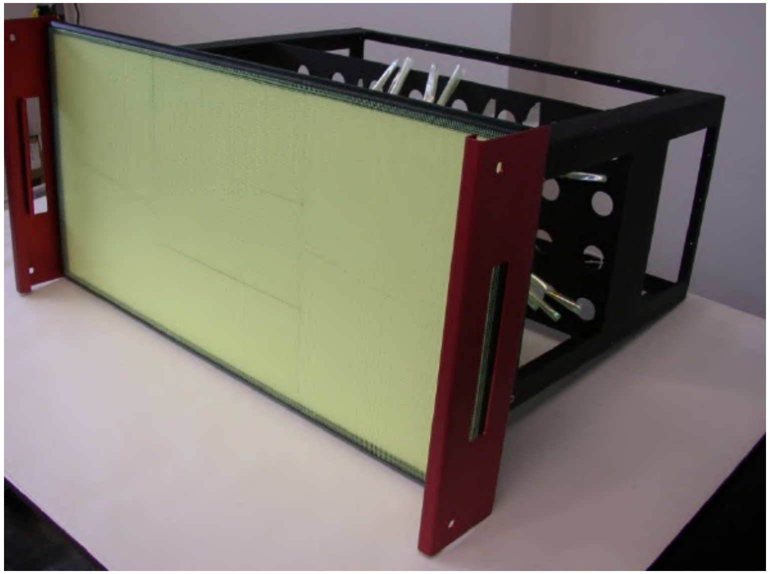


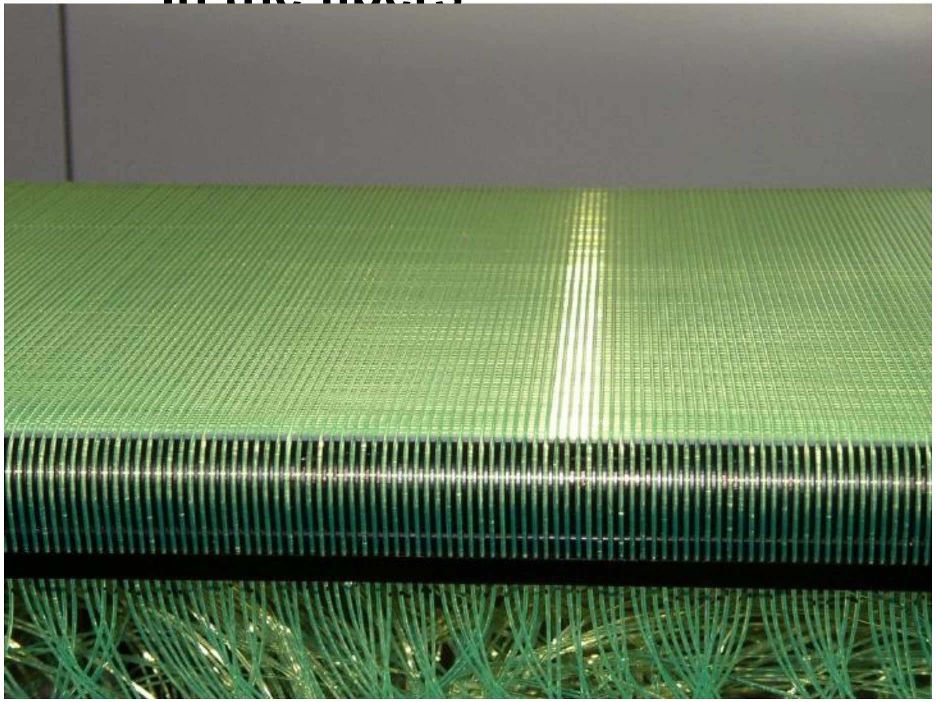


- **After passing through a thin aluminum window the neutron is captured in the LiFZnS:Ag scintillator**
- **Some of the blue light from the scintillator is shifted to green and trapped in the wavelength shifting fiber**
- **This light is detected by photomultiplier tubes and the coincidence determines the location on the scintillator**

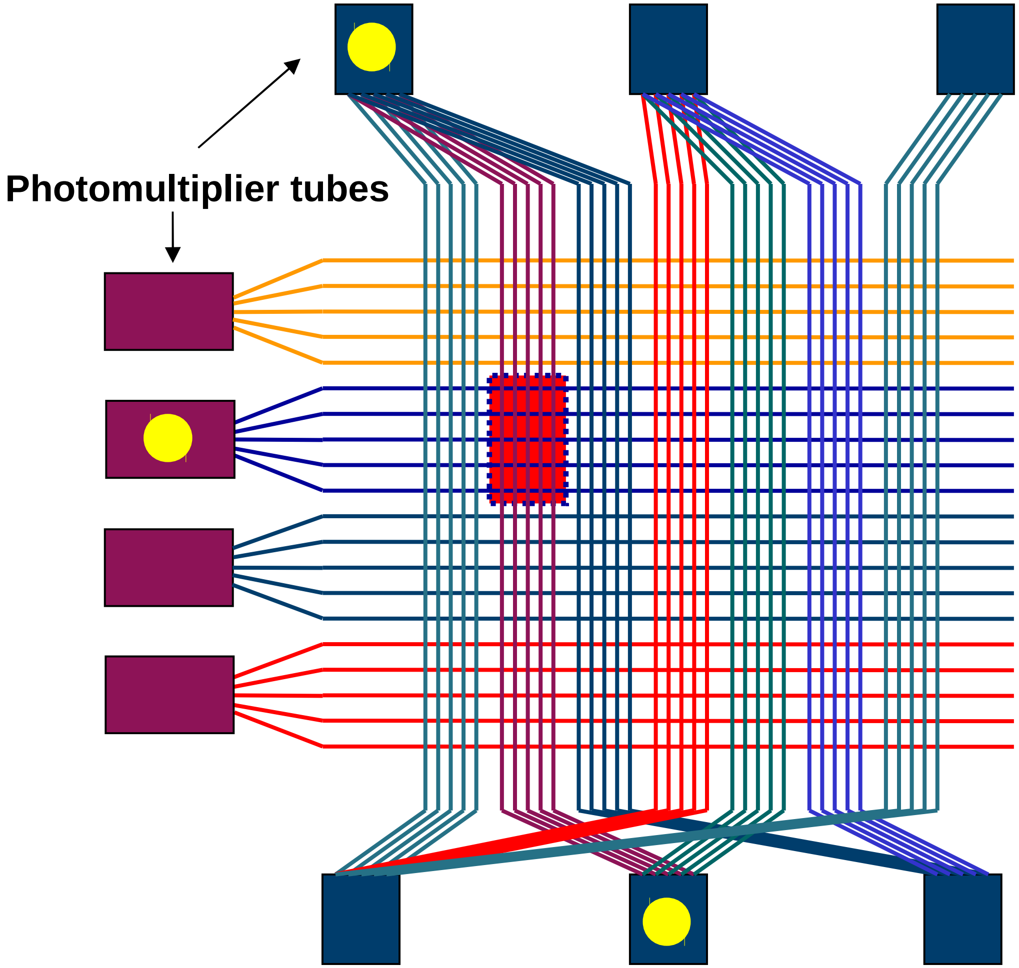
SSND Optical Readout

Blue scintillation
Light is shifted to
Green and
captured
In the fibers





Position Encoding (ISIS Concept)



m × ²Cₙ Coding

POWGEN3 & VULCAN

Production Modules:

Active area 772 x 386 mm² (0.3m²)

Pixels 5mm wide x 50mm tall

308 x 152 fibers

20 tubes encode in scattering plane

8 tubes define pixels out-of-plane

⁶LiF/ZnS:Ag scintillator

Double-clad wavelength-shifting fibers

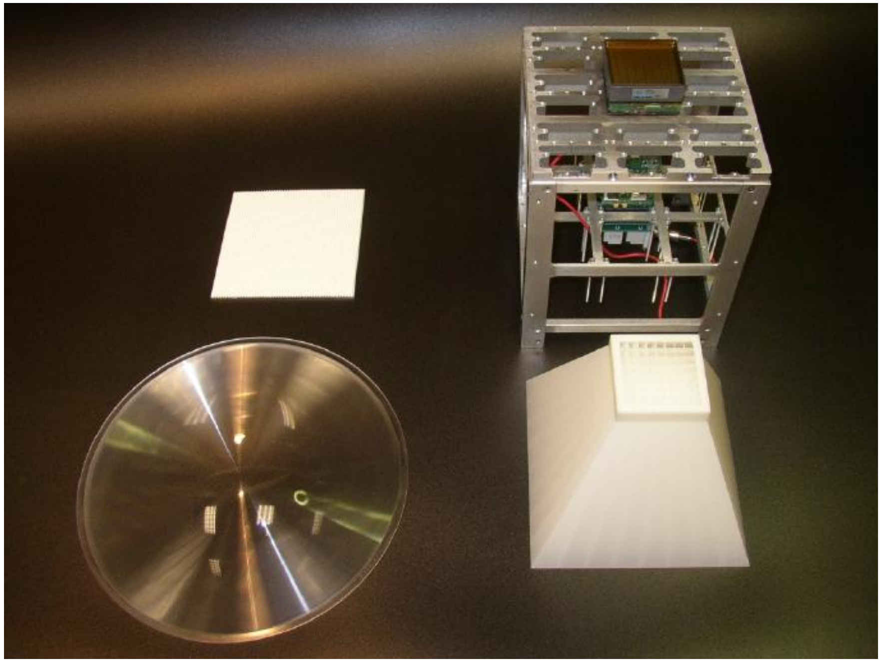
Green-enhanced PMTs

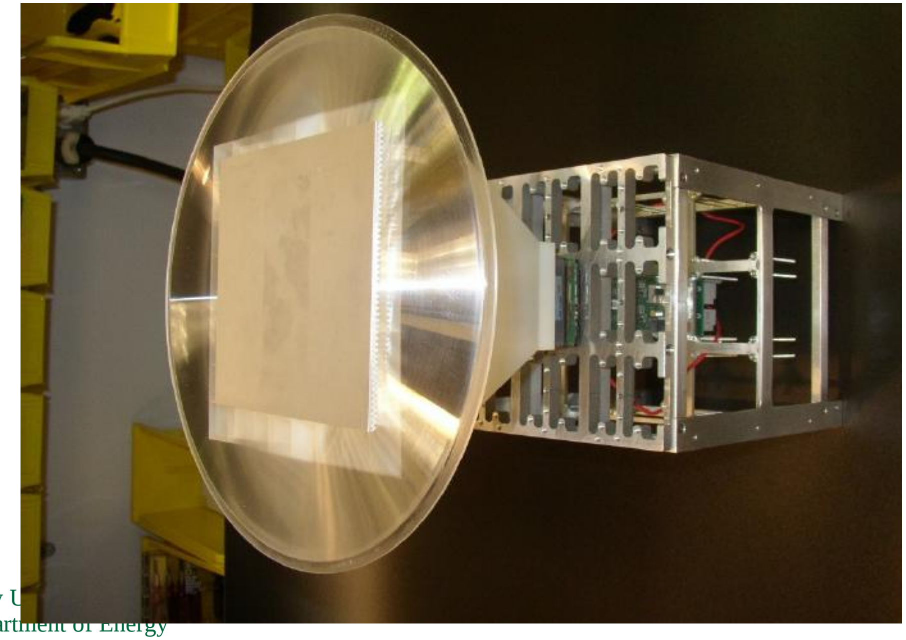
Light Guide Approach

- **View scintillator with segmented PMT**
- **Use a light guide to prevent crosstalk**
- **Prototype will have 2cm x 2cm pixels**
- **Use Hamamatsu H-8500, 64 anode tube**

Light Guide Prototype components

- **Four components:**
- **Scintillator**
- **Lens**
- **Guide**
- **PMT**





International Collaboration

Preliminary Agenda

"Helium-Group" – Meeting, Helmholtz-Zentrum Berlin, January 11-12, 2010

Monday, January 11th

Kolloquiumsraum (LMC)

Time	Preliminary Title	Speaker	Chair
13:30	Welcome (5')	Thomas Wilpert	
13:35	Introduction and status report (5')	Karl Zeitelhack	
Presentations of development programmes at the facilities			
13:40	SNS / HFIR (10' + discussion)	Ron Cooper	
14:00	J-Parc (10' + discussion)	Kazuhiko Soyama	
14:20	ISIS (10' + discussion)	Nigel Rhodes	
14:40	JCNS (10' + discussion)	Günter Kemmerling	
15:00	PSI (10' + discussion)	Oleg Kiselev	
15:20	NIST (10' + discussion)	Nick Maliszewskyj	
15:40	**Coffee break**		
16:00	ESS (10' + discussion)	Axel Steuwer	
16:20	ILL (10' + discussion)	Bruno Guerard	
16:40	HZ Berlin (10' + discussion)	Thomas Wilpert	
17:00	FRM II (10' + discussion)	Karl Zeitelhack	
17:20	Dubna (10' + discussion)	Vladimir Kruglov	
17:40	BNC (10' + discussion)	Laszlo Rosta	
18:00	End of session		
19:30	Dinner "Chopin" (Polish kitchen), Invitation by HZB		

Collaboration Continued

Preliminary Agenda

"Helium-Group" – Meeting, Helmholtz-Zentrum Berlin, January 11-12, 2010

Tuesday, January 12th

Kolloquiumsraum (LMC)

Time	Preliminary Title	Speaker	Chair
	Presentations of development programmes at the facilities (continued)		
09:00	Discussion on Presentations and search for joint activities		
10:30	**Coffee break**		
10:40	Cont. discussion / working group sessions		
12:00	**Lunch**		
13:00	Discussion on the preparation of the proposal for a common R&D programme		
15:30	End of meeting		

	Meeting with I. Anderson, R. McGreevy, M. Arai		
16:00	Discussion on IP issues and how to organize common R&D programme		
17:00	End of session		
19:00	Dinner in Ristorante "Salina", Invitation by HZB		

Division of Labor

- **Scintillator**
  - **ISIS**
  - **J-PARC**
  - **Juelich**
  - **ORNL**
- **BF3**
  - **Dubna**
  - **HZB**
  - **FRM2**
- **Straw tubes**
  - **ILL**
  - **ESS**

Discussion