SAND2007-7405P

Innovative High-Pressure Helium Neutron Detector

Gordon A. Chandler and Mark S. Derzon

APS-DPP Meeting Orlando, Florida

Wednesday, November 14th, 2007

Sandia National Laboratories

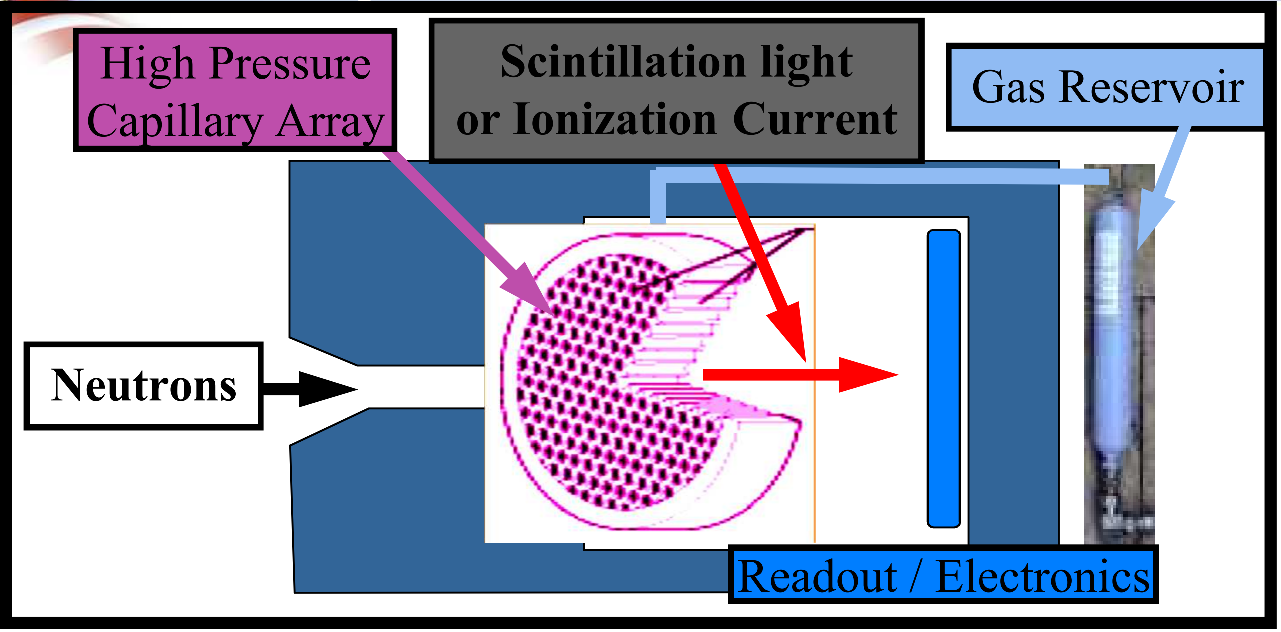
Abstract

Neutron detection systems are required to provide critical data for inertial confinement fusion experiments at Sandia National Laboratories. Critical measurements include Neutron spectroscopy, Neutron bang-time and Neutron Imaging. Present detector systems including scintillators coupled to photomultipliers, scintillating fiber arrays, diamond photoconductive detectors, and other systems, have been developed for these measurements. These detectors all have their limitations with regards to sensitivity, time response, energy resolution, spatial resolution and background rejection. An innovative high-pressure Helium detector is proposed that appears to have many beneficial performance characteristics with regards to making these neutron measurements in the high bremsstrahlung environments found in high energy density physics experiments on the fast pulsed power facilities at Sandia. Calculations of the performance characteristics of these detectors will be presented.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the U.S. Dept. of Energy under contract No. DE-AC04-94AL85000.

Sandia National Laboratories

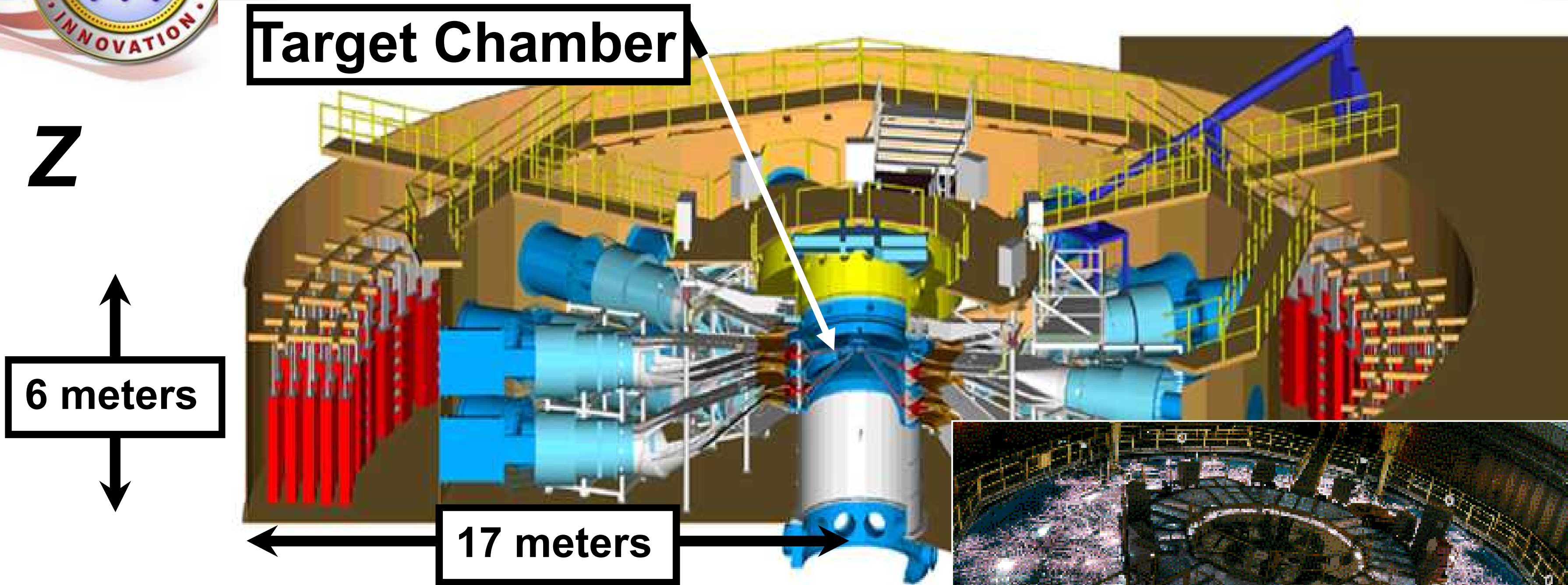
A high-pressure helium neutron detector has many favorable characteristics

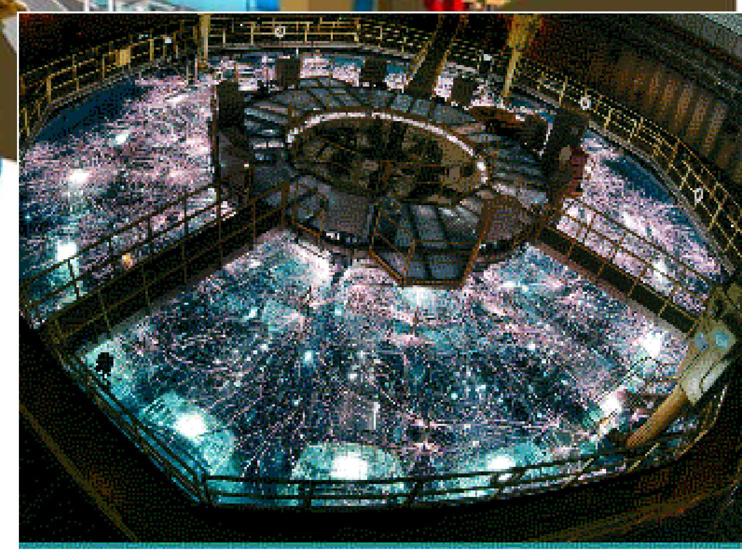


1. This detector system utilizes neutron reactions with high-pressure Helium gas to generate detectable scintillation photons or charged particles
2. Sandia's MEM's and fluidics technologies allows for extremely high pressure fluid and gas fills of capillary arrays, ~2000 atm, yielding enhanced detection efficiency with the greater gas density
3. A compact pixilated detector results which is naturally compatible with neutron imaging as well as neutron spectroscopy and burn/bang diagnostics
4. This detector has a high neutron to gamma detection sensitivity due to the high neutron cross-sections, low Z Helium gas fill, favorable ion to electron scintillation efficiency and long electron deposition range

The Z accelerator efficiently couples energy into neutron generating loads

Z





Parameter	Z	Z_Refurb*
Stored Energy (MJ):	11.5	20
Peak Current (MA):	20	26
Peak X-ray Energy (MJ):	1.6	2.7
Peak X-ray Power (TW):	230	350
Deuterium Gas Puff Yields:	3×10^{13}	9×10^{13}

* Predicted

High energy bremsstrahlung radiation generated: ~ 2.5 kilorads @ one meter!

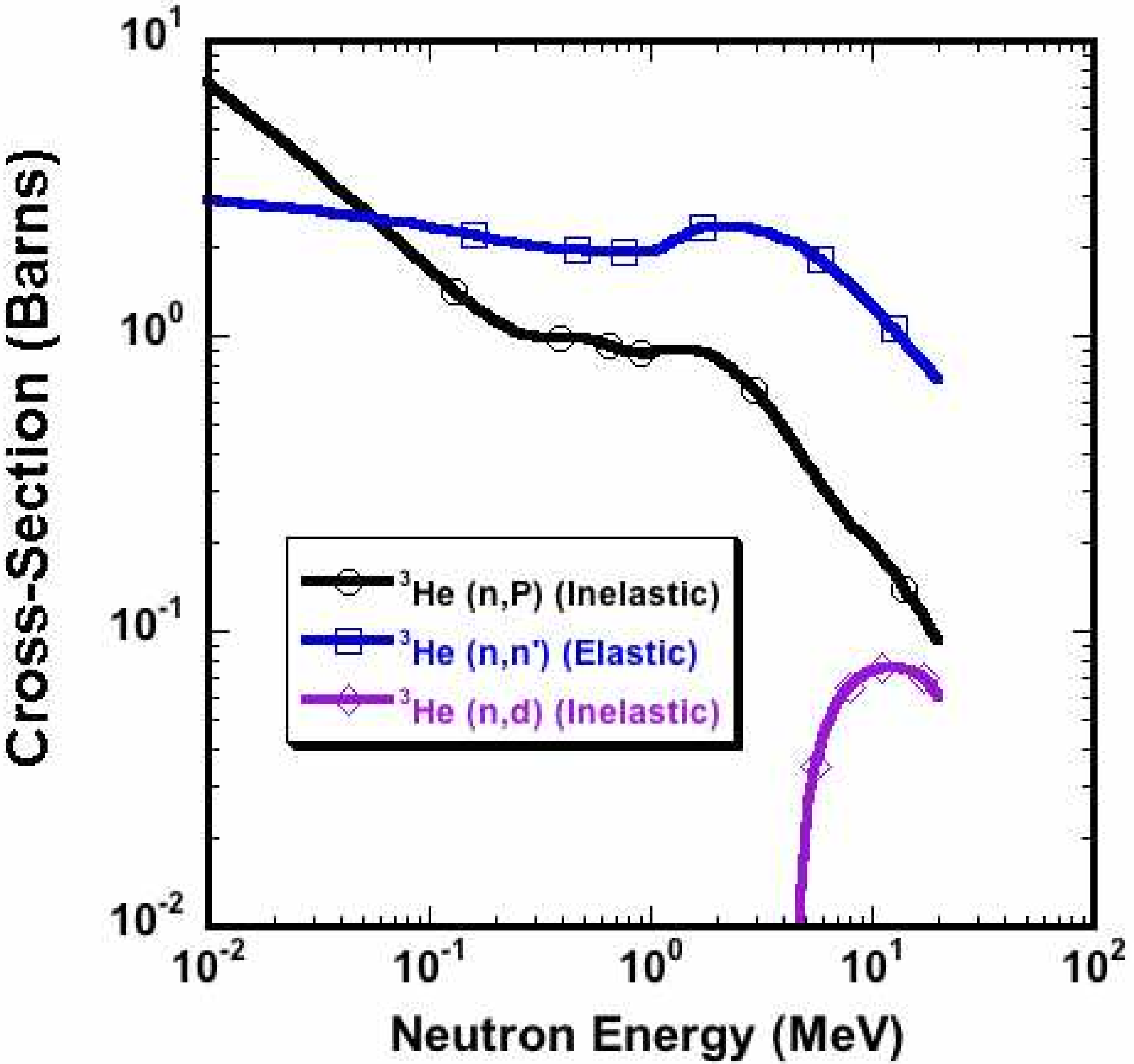
A number of operating modes are envisioned for these detectors

Operating Mode	Detector Scale Size:	Time Response (DT neutron limited)
Imaging	Diameter: 8 cm; Thk: 5 cm Capillary ID : 100 um	~10's of ns
Bang-Time	Diameter: 2 cm; Thk: 1 cm Capillary ID : 500 um	0.2 ns Rise-time
Reaction History	Diameter: 2 cm; Thk: 0.2 cm Capillary ID : 500 um	40 ps Rise-time
Spectroscopy - Single Hit NTOF	Diameter: 8 cm; Thk: 0.2 cm ?? Capillary ID: 500 um Capillary #: 1400	40 ps Rise-time

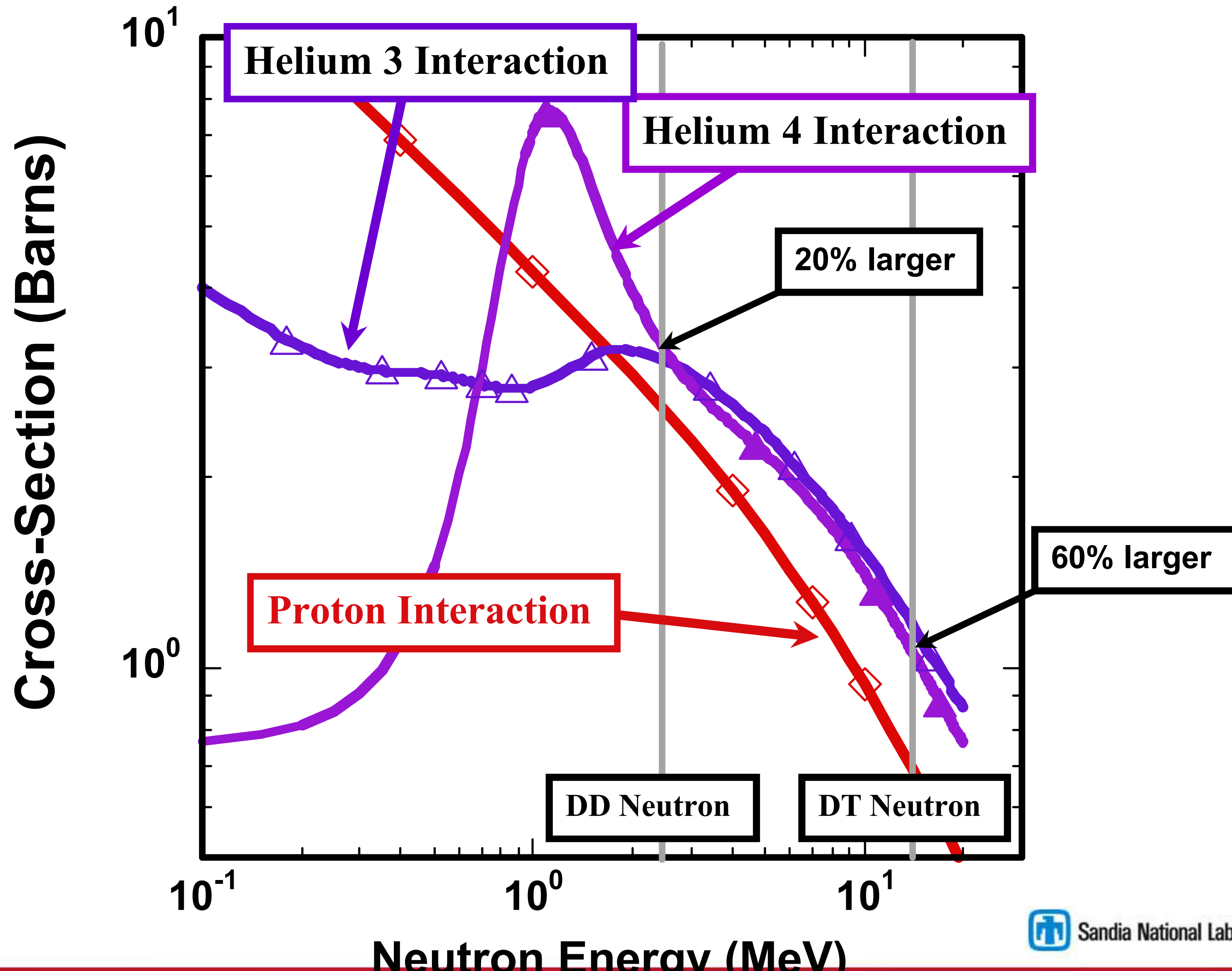
Note: Actual rise-time measurements are needed

Helium-3 neutron detectors have mav positive features

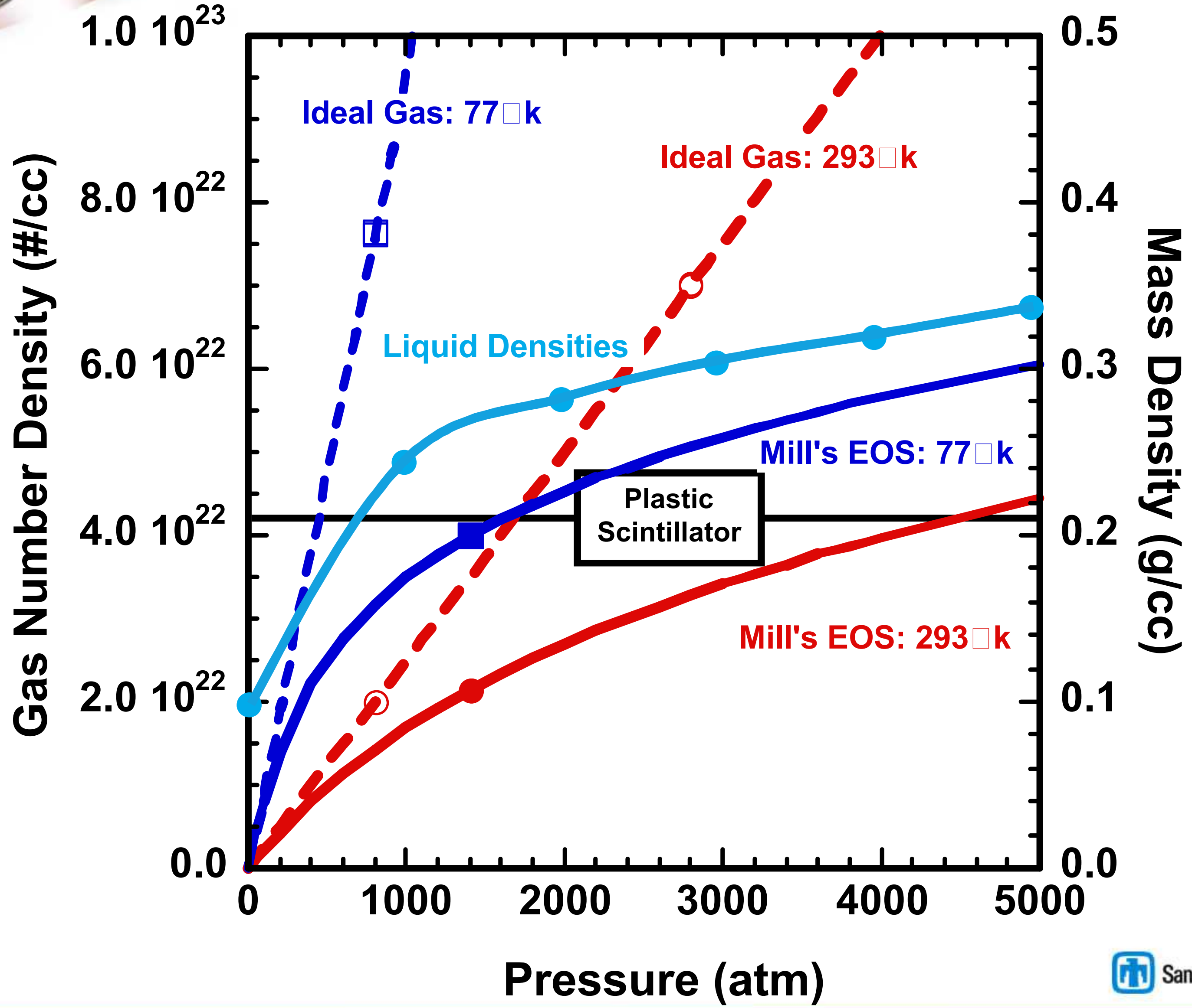
- Highest low energy cross-section
- Positive Q-value for in-elastic reaction(764 keV)
- Low Bremsstrahlung sensitivity



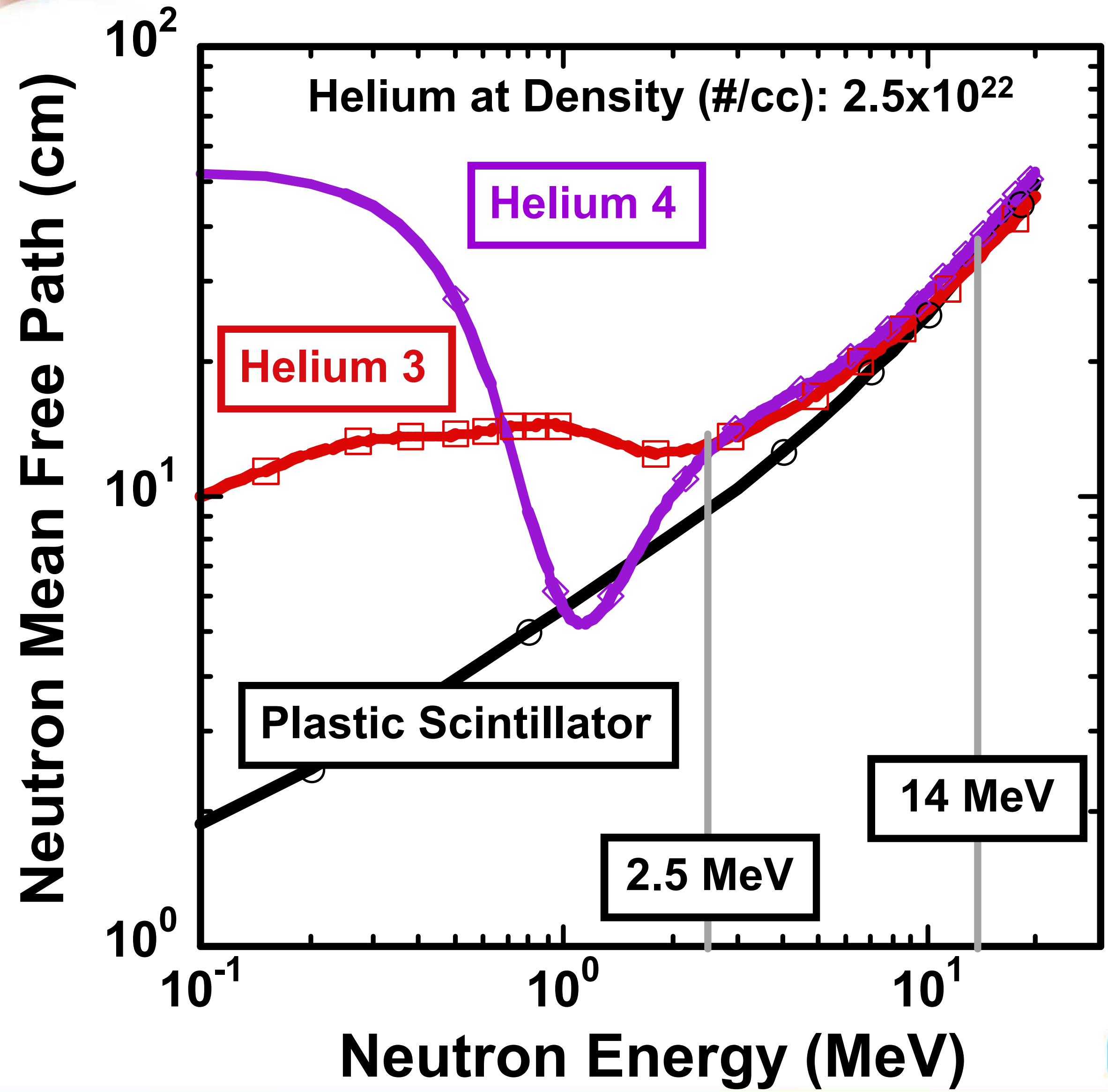
DD and DT neutron cross-sections are larger for helium then for protons!



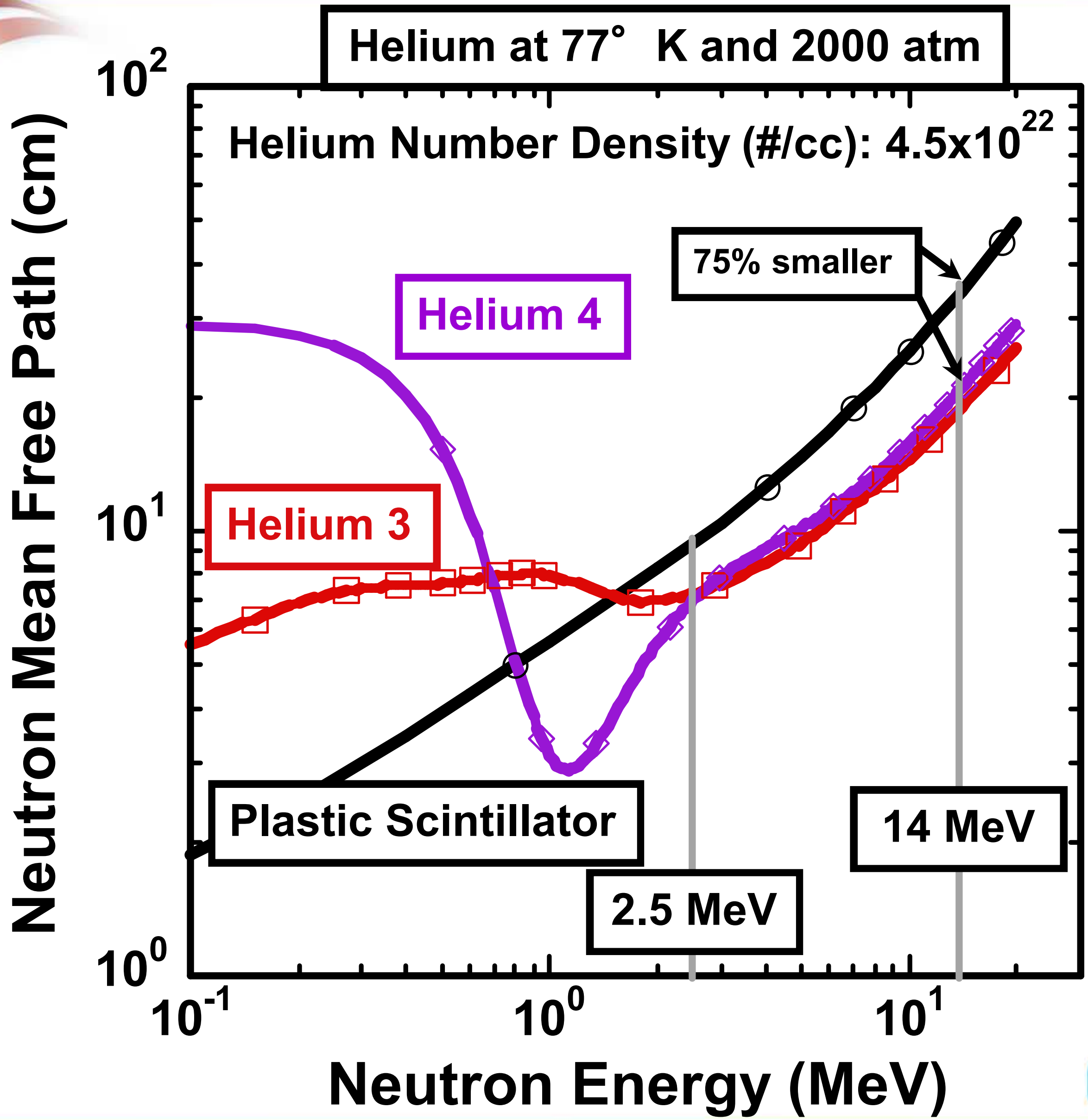
The helium density can be higher then the hydrogen density in a plastic scintillator



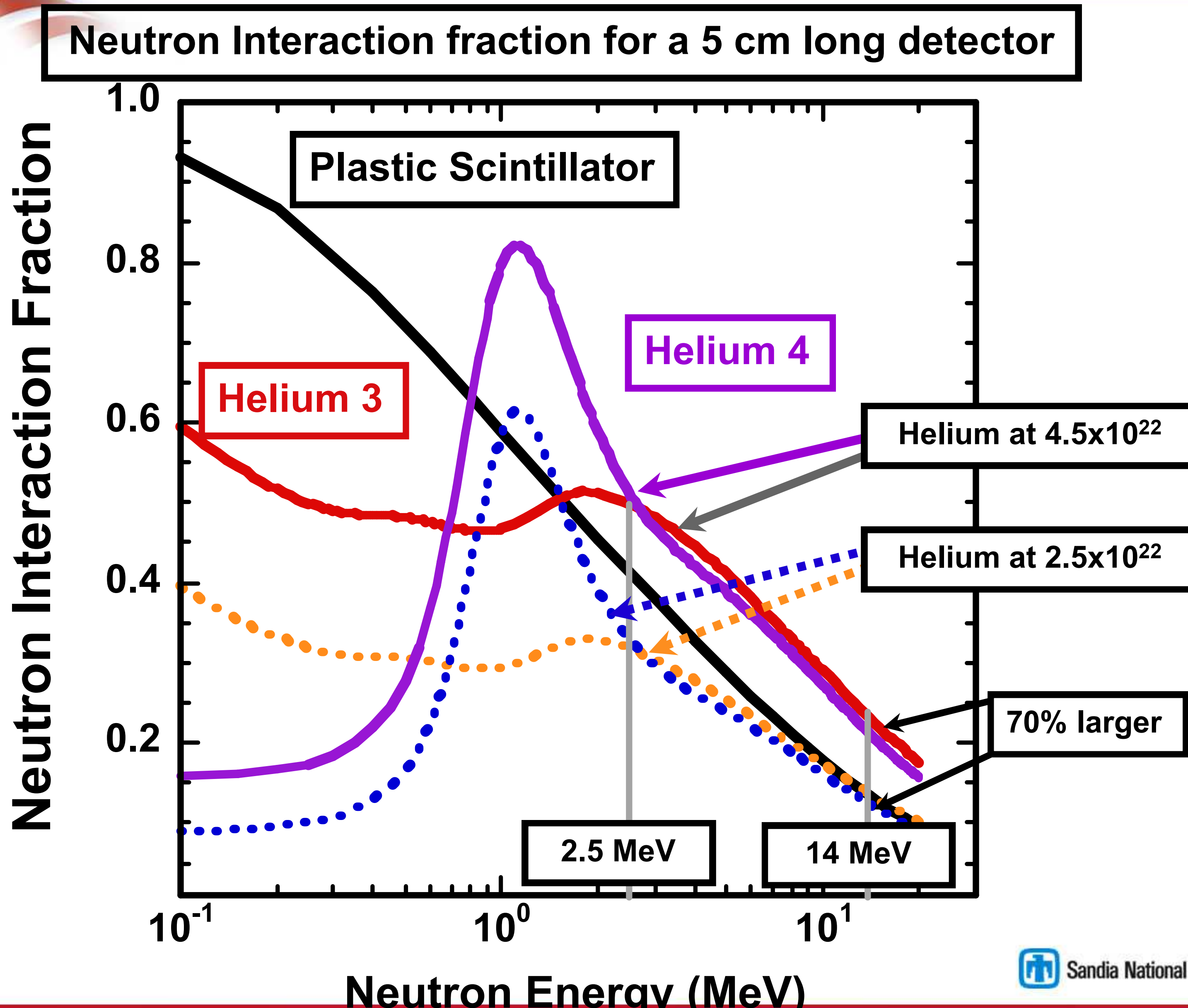
The DD and DT mean-free paths are similar for plastic scintillator and helium at 20°C and 2000 atm



The DD and DT mean-free path in low-temperature helium is ~70% smaller than plastic scintillator

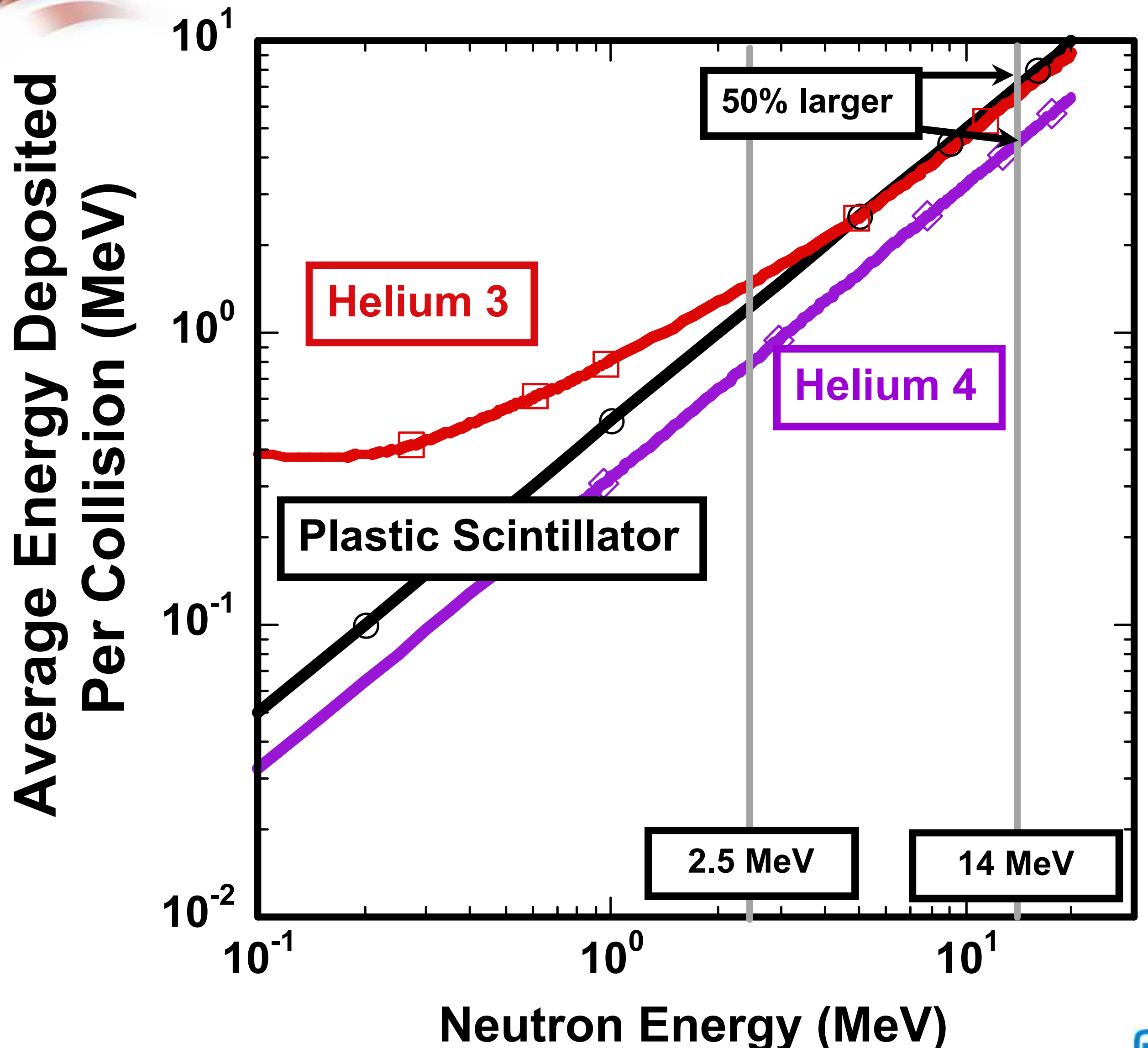


The number of DD and DT neutron interactions can be significantly larger in helium then in plastic



Sandia National Laboratories

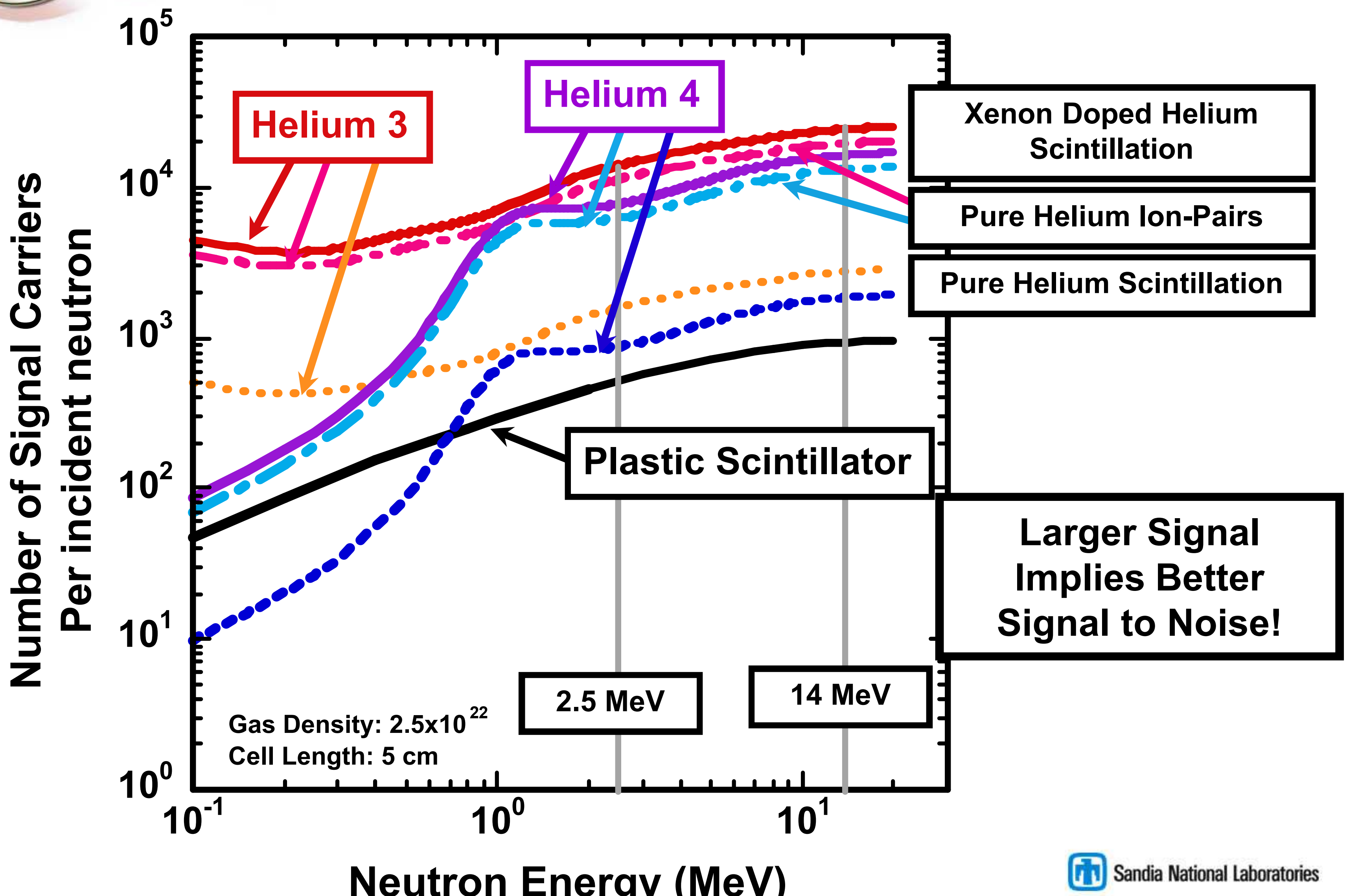
The average energy deposited for MeV neutrons for helium and plastic scintillator is similar



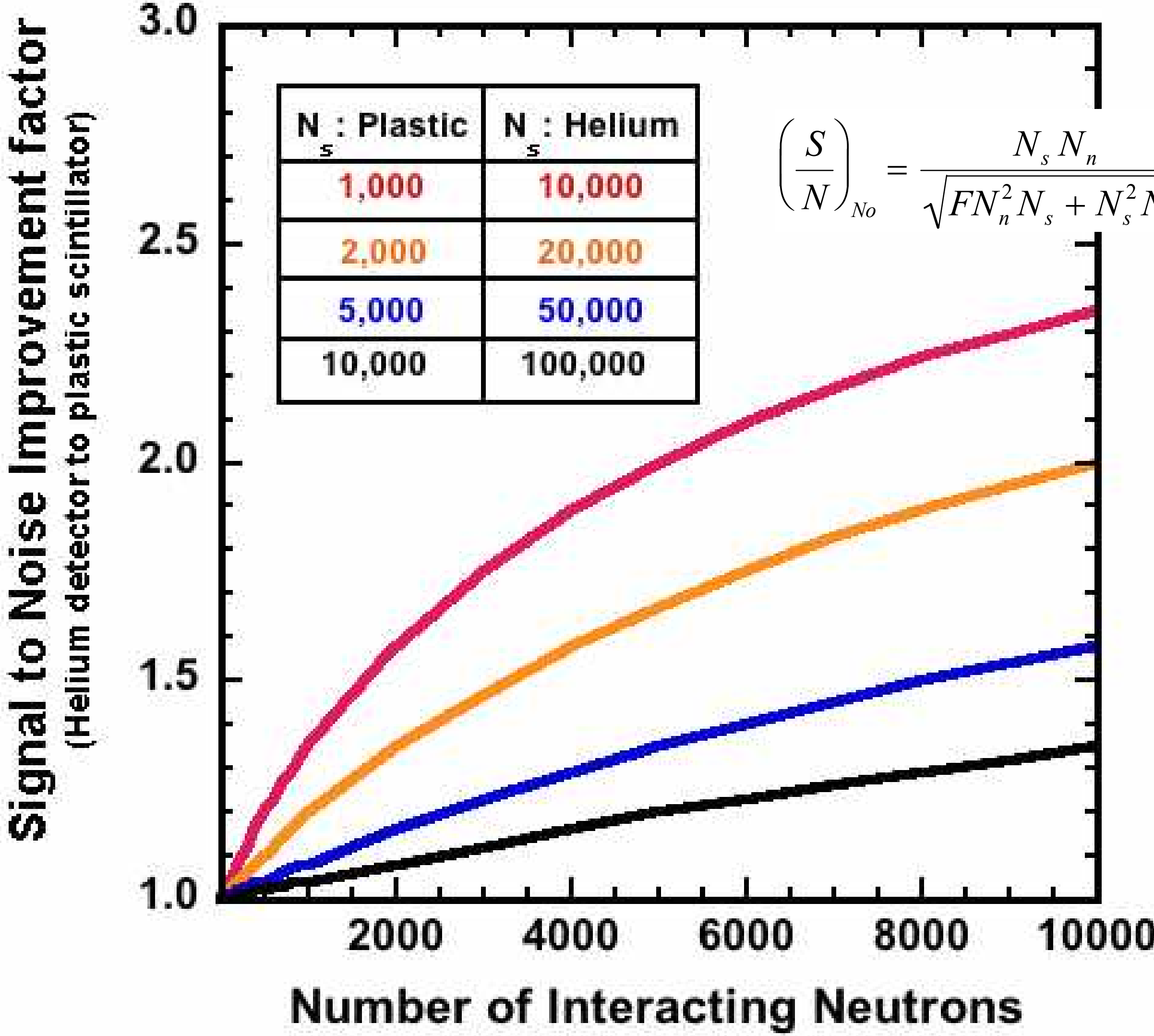
The energy required for a signal carrier in helium is significantly less then for plastic scintillators

Target:	Helium	Helium doped with Xenon	Protons in Plastic Scintillator
Energy / Photon	300 eV	34 eV	1000 eV
Energy / Ion - pair	42.3 eV	42.3 eV	N/A

A factor of 10 signal enhancement for helium vs plastic scintillator for MeV neutrons is possible!



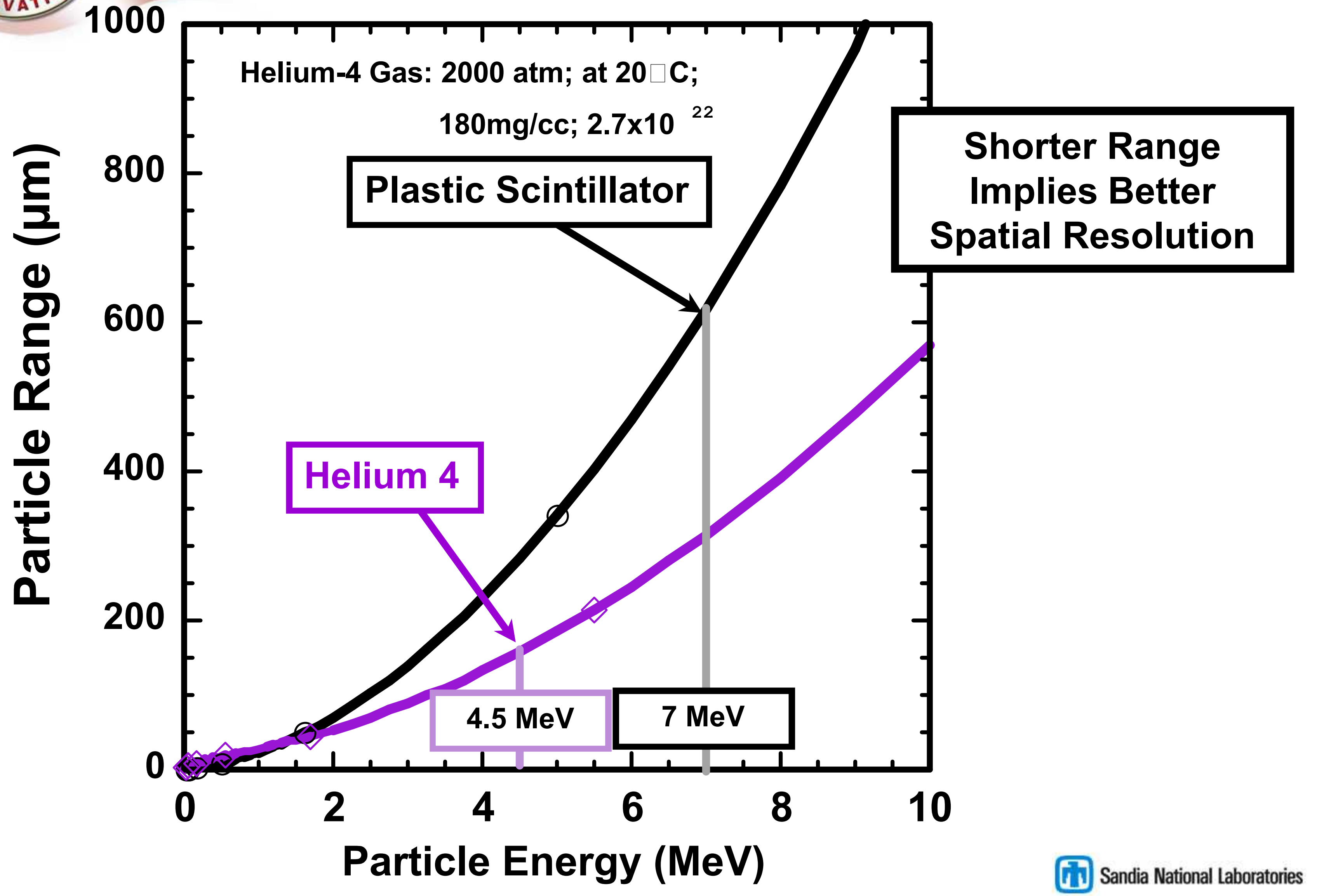
Signal to noise enhancements can be significant



N_s : Plastic	N_s : Helium
1,000	10,000
2,000	20,000
5,000	50,000
10,000	100,000

$$\left(\frac{S}{N}\right)_{No} = \frac{N_s N_n}{\sqrt{FN_n^2 N_s + N_s^2 N_n}} = \frac{\sqrt{N_s N_n}}{\sqrt{FN_n + N_s}}$$

For DT neutrons the recoil particle range is four times less in helium then in plastic scintillator!

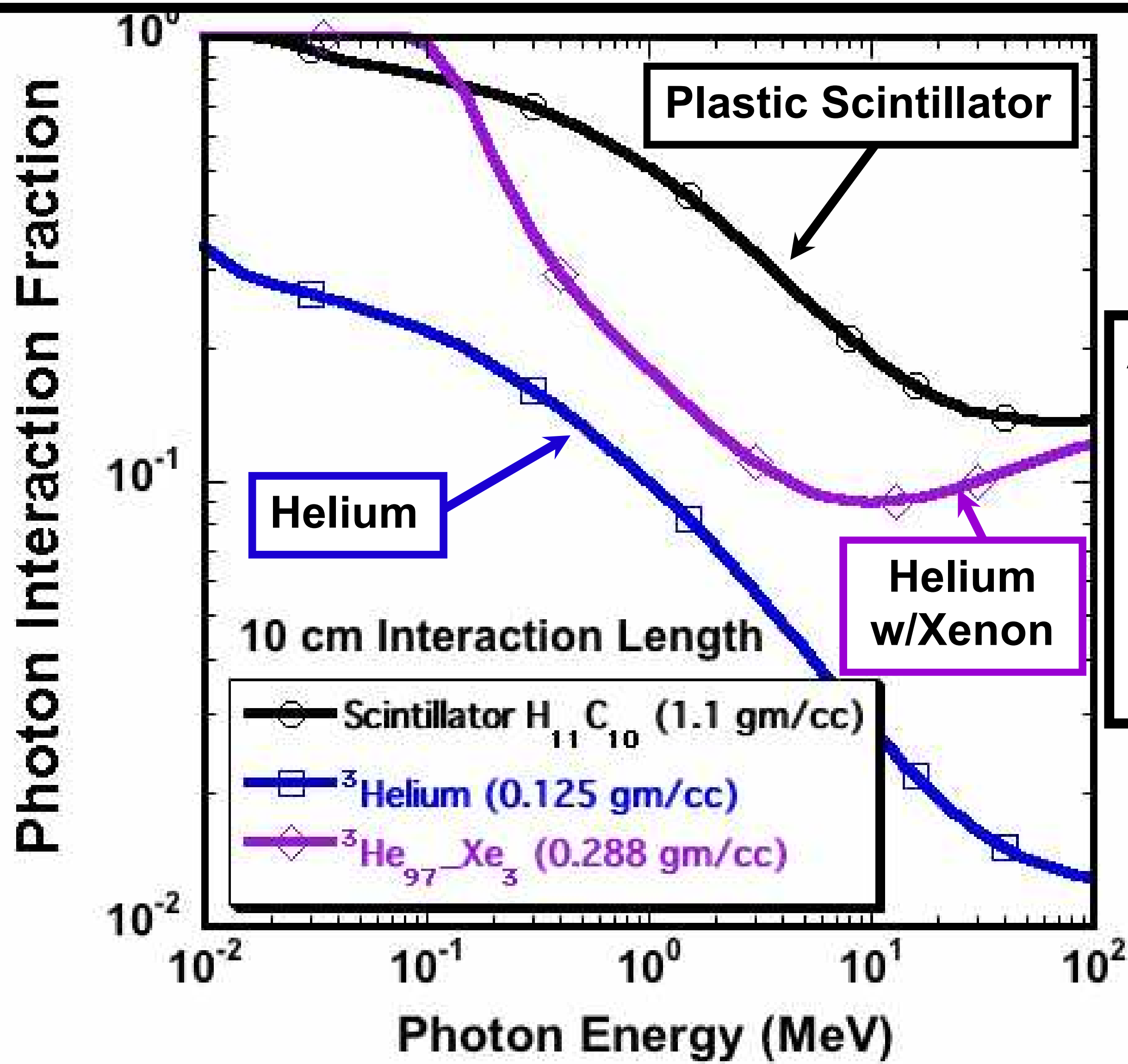


Sandia National Laboratories

H_BC418_He4_He_plt.qpc

A helium detector is insensitive to Bremsstrahlung radiation compared with plastic scintillator

Helium detector ~10x less sensitive compared with Plastic Scintillator



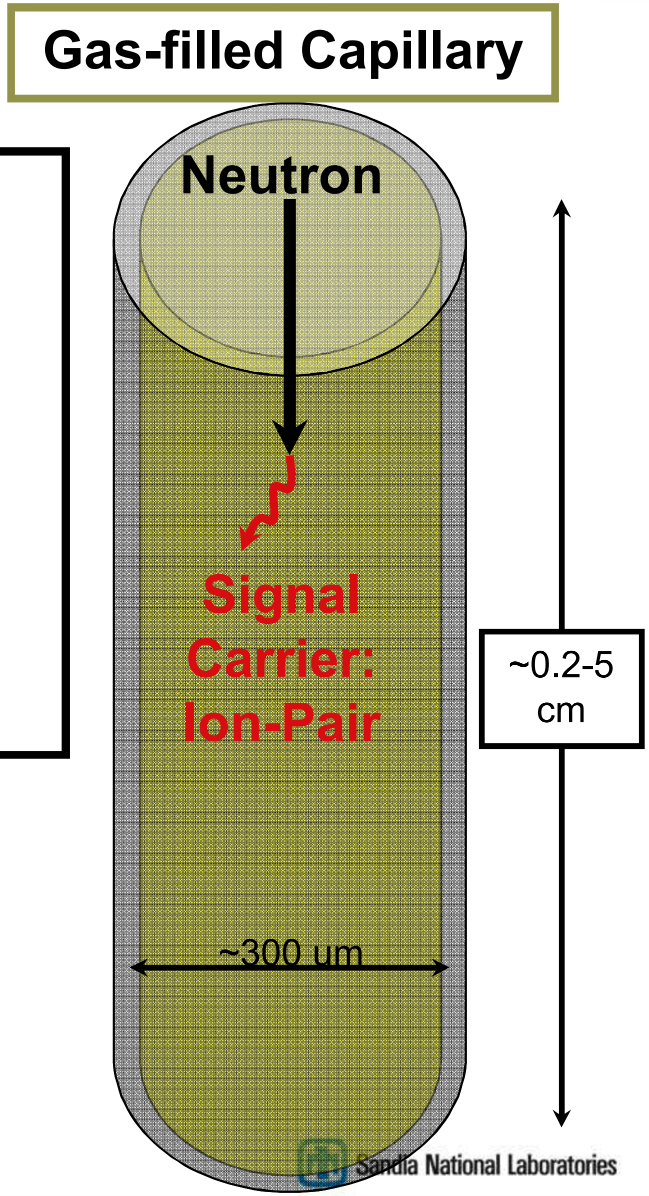
Another factor of ten improvement Due to:

- **Significantly longer Electron Range**
- **Improved Particle to Electron Light Yields in Helium**

Efficient collection of the ion-pairs is a major technical issue

Long Aspect Ratio Capillaries add challenges collection of signal carriers:

- Ion-Pair charge collection
  - Charge diffusion along capillary length
  - Charge collection times
- Solution: Embed electrode structures along length of the capillaries



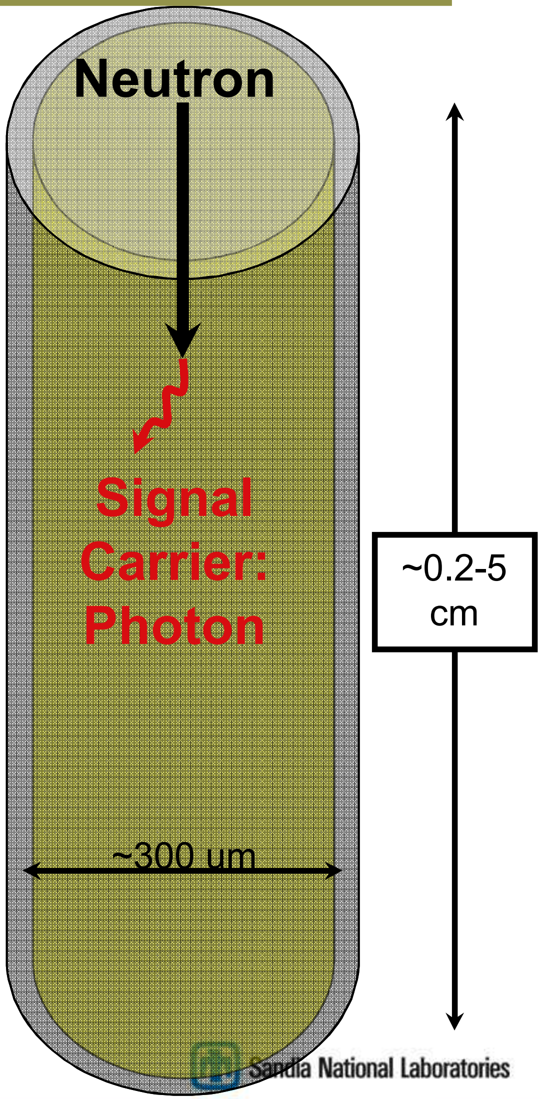
Efficient collection of the scintillation photons is a major technical issue

Long Aspect Ratio Capillaries add challenges collection of signal carriers:

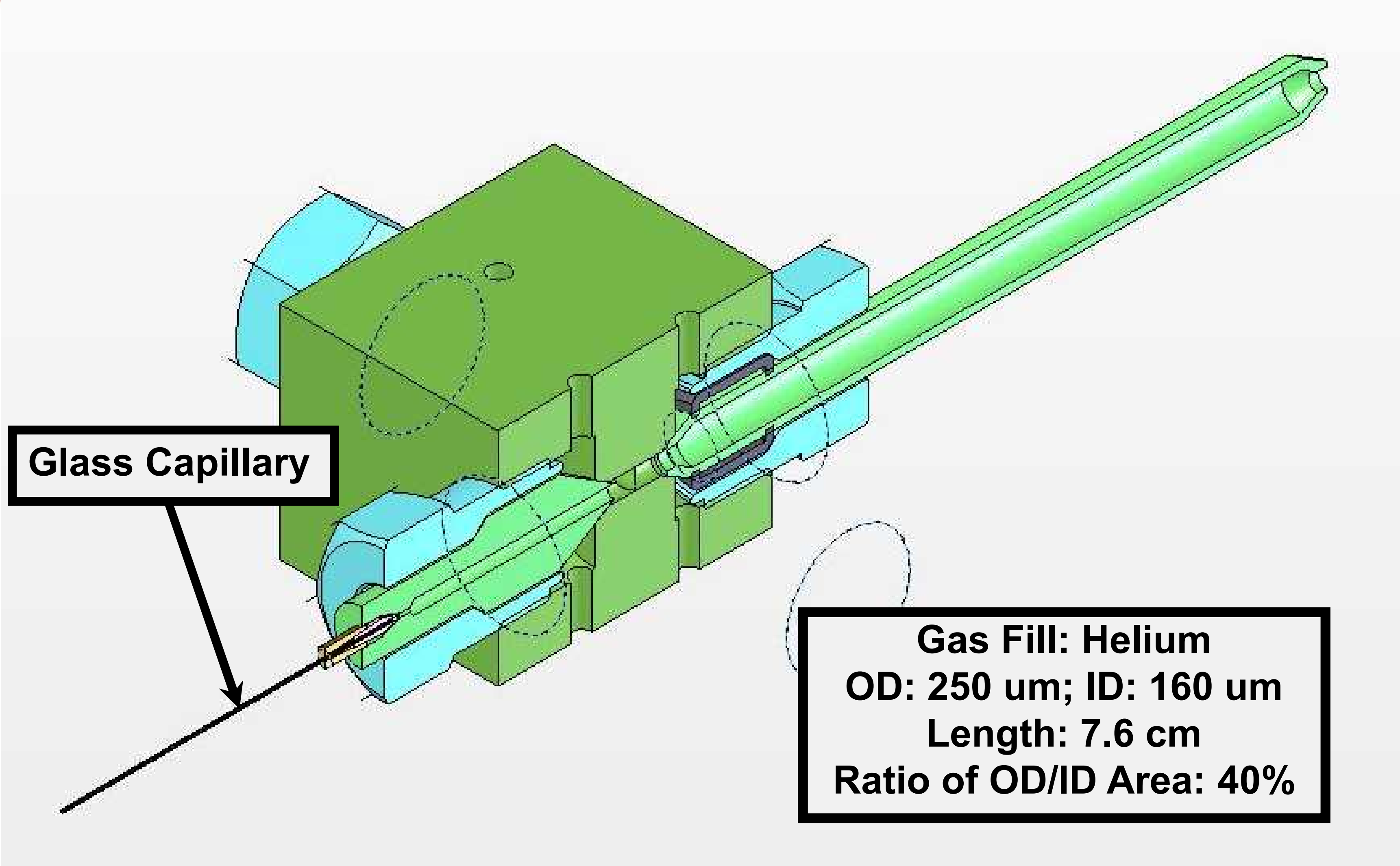
- Ultraviolet Scintillation light collection
  - Absorption in uncoated walls
    - Solution: Develop highly reflective coatings, >99.5%, for inner surfaces
  - Low index of refraction for gas fill:
    - Standard fiber-optic transport doesn’t work
    - Solution 1: Use Bragg fiber reflection
    - Solution 2: Use Photonic Band-gap reflection

No known supplier for capillary arrays

Gas-filled Capillary

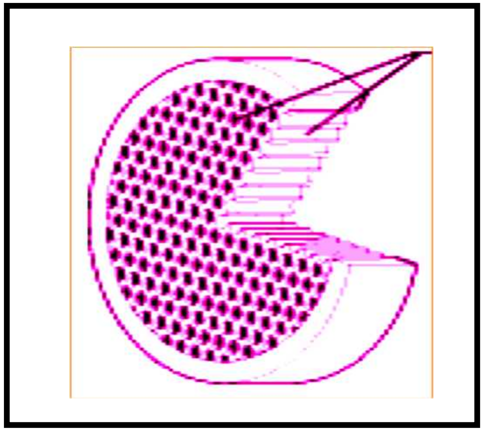


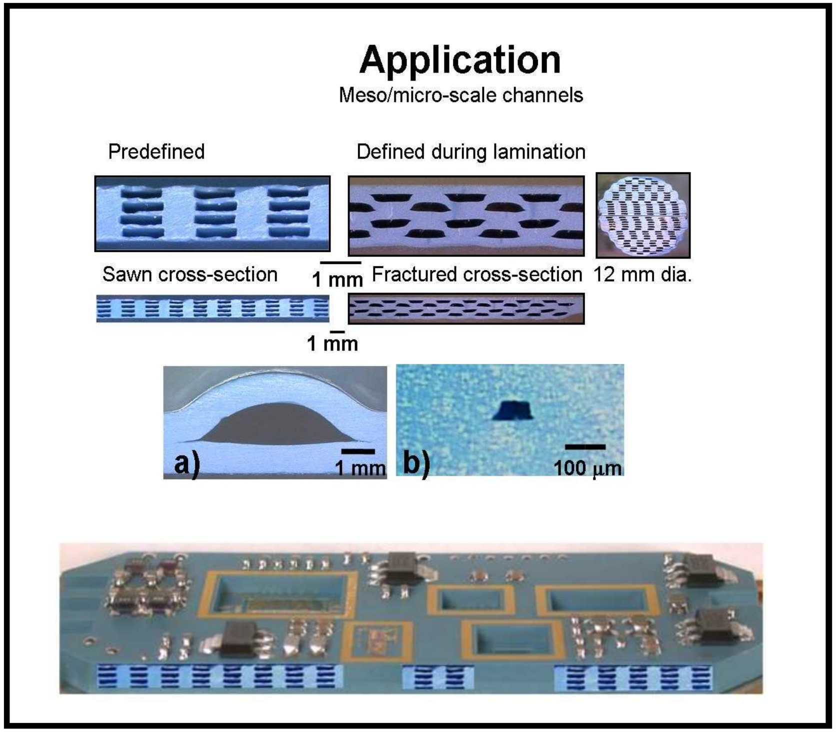
Individual Glass Capillaries have been pressured over 2700 Atm

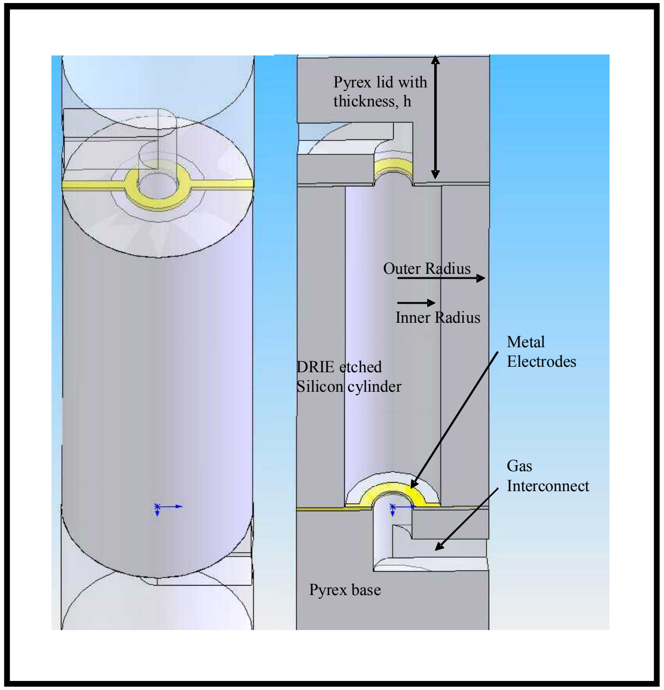


Three fabrication methods are being considered

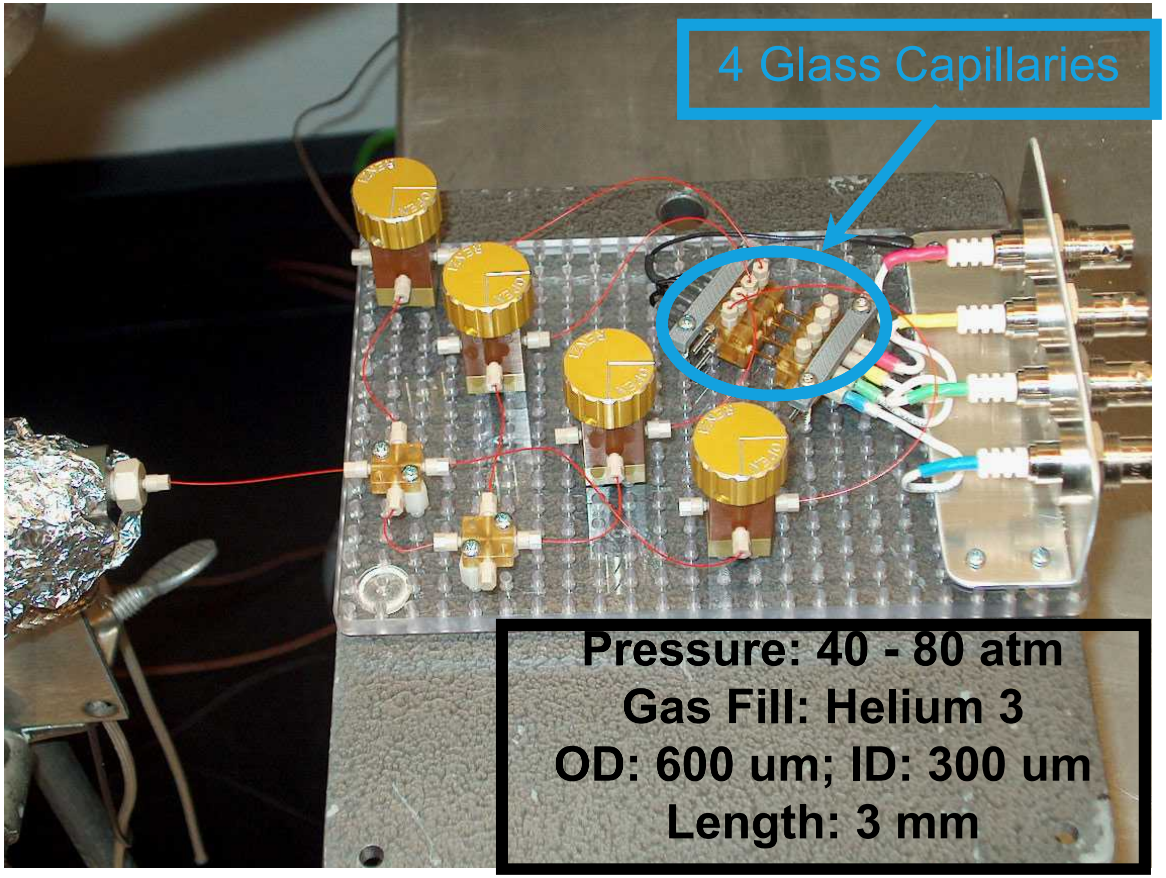
- Glass Capillaries / Collimated holes
- Low-Temperature Co-Fired ceramic
- Silicon Fabrication







Tests of Individual Capillaries using Electrical Readout is in progress



Device Picture – device provided by R. Renzi, 8125

Key Diagnostic Development Issues that need to be addressed

- Fabrication of Capillary arrays consistent with the pressure handling and the diagnostic requirements
- Fabrication of Capillary Arrays consistent with the Diagnostic Readout Technologies
  - Scintillation Detector: Scintillation light Collection efficiencies
  - Ionization Detector: Capillary Electrodes for efficient Electron and Ion Collection
- Measure the response of these detector modalities over this new operating regime in pressure and packaging in terms of Sensitivity and Time-Response
- Improved modeling of the detector response including the effects of the mechanical structures on the detector performance

Key Accomplishments

- The merits of high-pressure helium based neutron detector systems compared with standard organic scintillator based systems was developed
- Improvements by a factor of ten in the number of signal carriers was shown
- Signal to Noise improvements of a factor of two for certain imaging applications developed
- Reduction in the sensitivity to bremsstrahlung radiation by factors of two to seven times shown
- Spatial resolution enhancements of a factor of four indicated
- Future development work elucidated