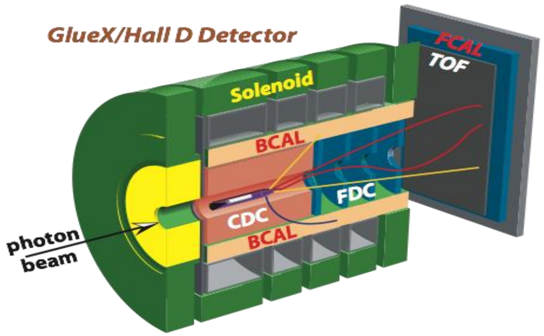


Jefferson Lab

Beamline Commissioning and Radiation

A. Somov, Jefferson Lab

E12-19-003
Experiment Readiness Review
March 31, 2020

Outline

- Beam Commissiong (charge 7)

Are the beam commissioning procedures and machine protection systems sufficiently defined for this stage?

- Radiation level (charge 4)

What is the impact of the expected neutron radiation on GlueX detector components such as the SiPMs? Is any local shielding required? Are the radiation levels expected to be generated in the hall acceptable?

Photon Beam Requirements

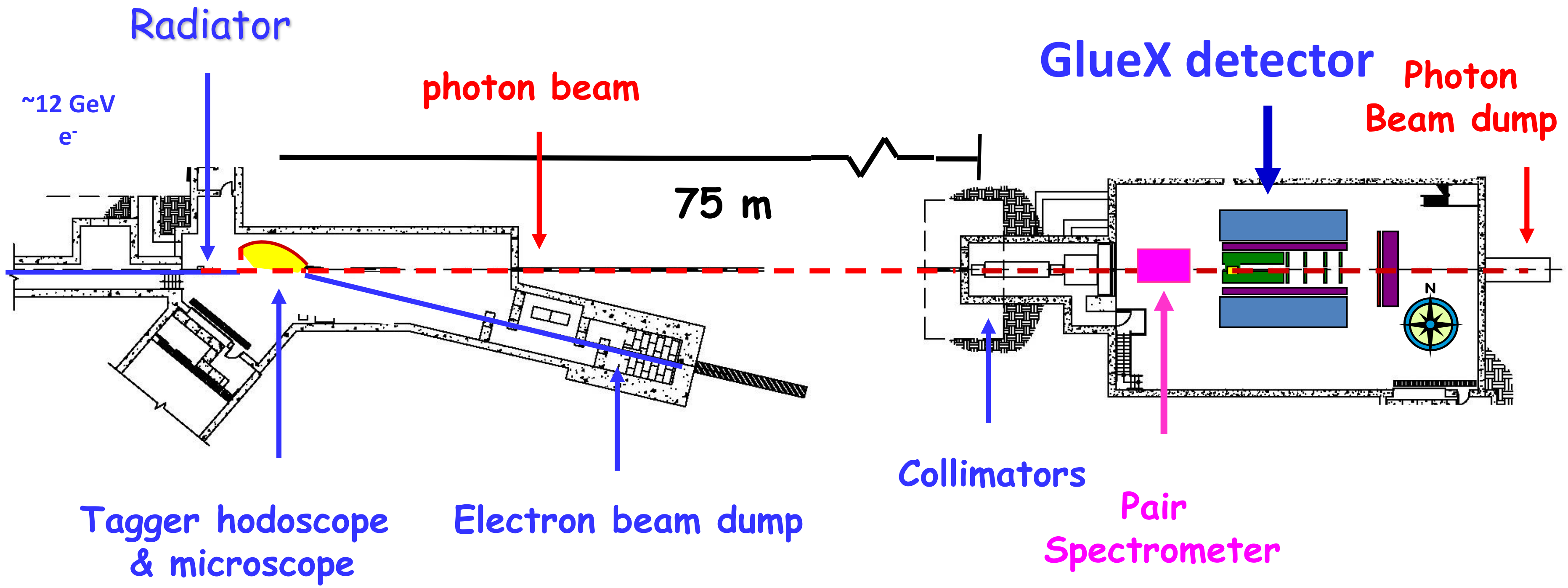
Experiment	Energy Range (GeV)	Polarization	Flux in the energy range of interest γ/ sec	Flux on target (0.012 – 11.7 GeV) γ/ sec
GlueX Design	8.4 - 9.1	40 %	10^{8}	$1.8 \cdot 10^{9}$
GlueX II	8.4 - 9.1	40 %	$5 \cdot 10^{7}$	$9 \cdot 10^{8}$
This experiment	8.4 - 9.1	40 %	$2 \cdot 10^{7}$	$3.6 \cdot 10^{8}$

	This experiment	*GlueX II*
Electron beam current:	140 nA	350 nA
Radiator thickness:	$4 \cdot 10^{-4}\ X_0$	$4 \cdot 10^{-4}\ X_0$
Collimator diameter:	5 mm	5 mm

Photon flux on target is about 2.5 smaller than GlueX II flux (5 times smaller than GlueX designed flux)

Hall D Photon Beam Line

Use standard Hall D beam line equipment for SRC / CT !

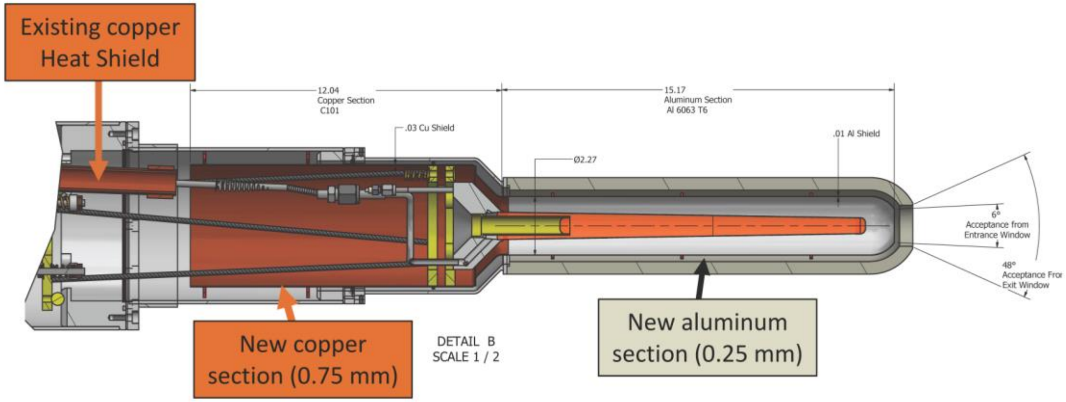


Targets

See C. Keith talk

- LD (LHe) target. Standard GlueX target cell and cryogenic system
  - LHe targer was used by Hall D PrimEx expeiment

- Carbon target
  - Similar to PrimEx Be target



SRC/CT Beamline Summary

- 12 GeV polarized photon beam has been successfully used by the GlueX experiment in 2016 - 2019

- Typical GlueX beam configurations:
  - electron beam current 100 – 350 nA (data production)
  < 5 nA (PS calibration)

- Beamline equipment installed in Hall D is ready to use by the SRC/CT experiment

- Photon beam conditions used for the GlueX data production satisfied specifications of the RC/CT experiment

- Beam delivery/monitoring procedures and machine protection systems are the same as for the GlueX experiment

Radiation Level

Charge 4

- Radiation damage to Silicon Photomultipliers (SiPM) produced by neutron background
- Radiation level in Hall D

SRC Targets and Run Period

Target	Thickness [cm] / % X_0	Atoms	Run Time (days)
LH	30 / 3.4	$1.28 \cdot 10^{24}$	GlueX
D	30 / 4.1	$1.51 \cdot 10^{24}$	4.5
^{4}He	30 / 4.0	$5.68 \cdot 10^{23}$	1
^{12}C	1.9 / 7	$1.45 \cdot 10^{23}$	7

- SRC/CT photon flux is 5 times smaller than GlueX designed flux
- The largest neutron background will be produced on liquid deuterium and helium targets

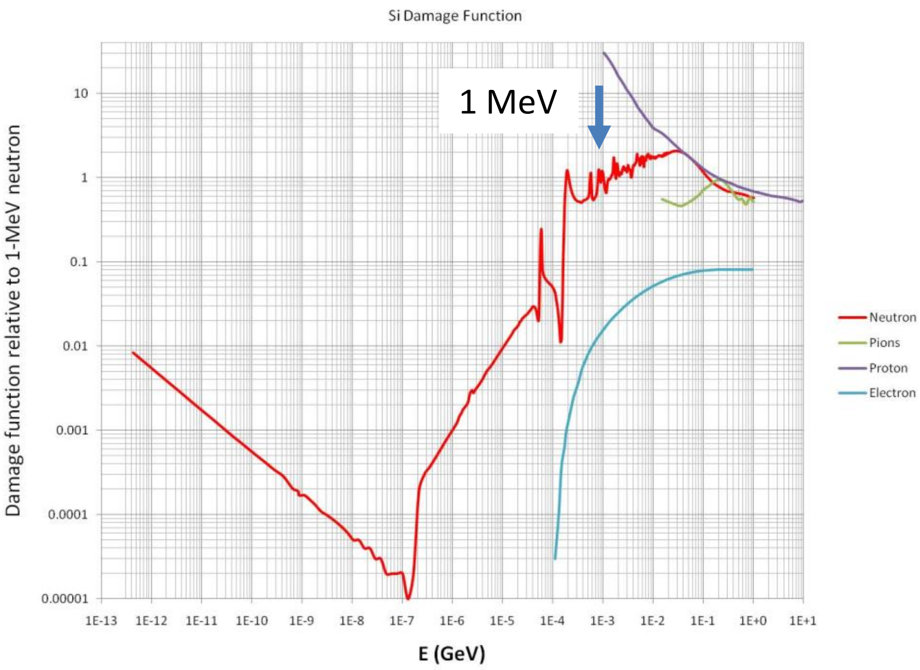
Radiation Damage to SiPM

- displacement of atoms in the lattice associated with the kinetic energy release to matter

- characterized by damage function (similar to biological damage curve)

- in simulation, convert particle fluence to the equivalent fluence of 1 MeV neutrons using the damage function

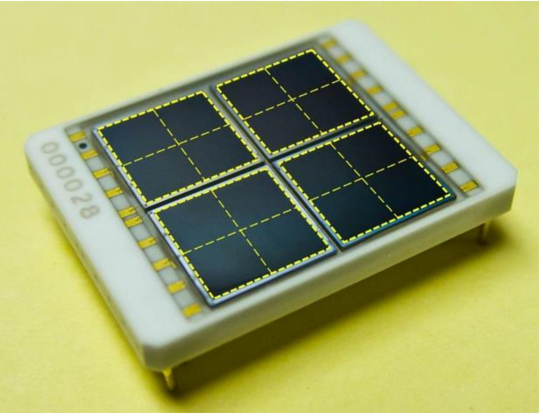
- largest damage is produced by neutrons with $E_{kin} \geq 1$ MeV



Increase of the SiPM dark noise

Silicon Photomutipliers in Hall D

Barrel Calorimeter



- array of 3 mm x 3 mm SiPMs (3840 sensors)
- calorimeter design allows for a factor of 5 increase of the dark rate
- radiation hardness studied using Am-Be neutron source and beam test setup in Hall A

https://halldweb.jlab.org/wiki/index.php/SiPM_Radiation_Hardness_Test
NIM A **698** (2013) 234

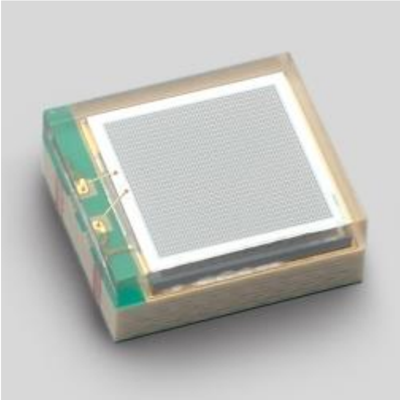
(critical dose 32 rem, 1 rem $\sim 3.3 \cdot 10^7$ n_{EQ} / cm^2 neutron 1 MeV equivalent fluence)

- expected lifetime at GlueX designed luminosity (10^8 γ / sec)

8 - 10 years for Hydrogen
5 - 7 years for Helium

(assuming the experiment operation efficiency of 33%)

Silicon Photomutipliers in Hall D



Start Counter

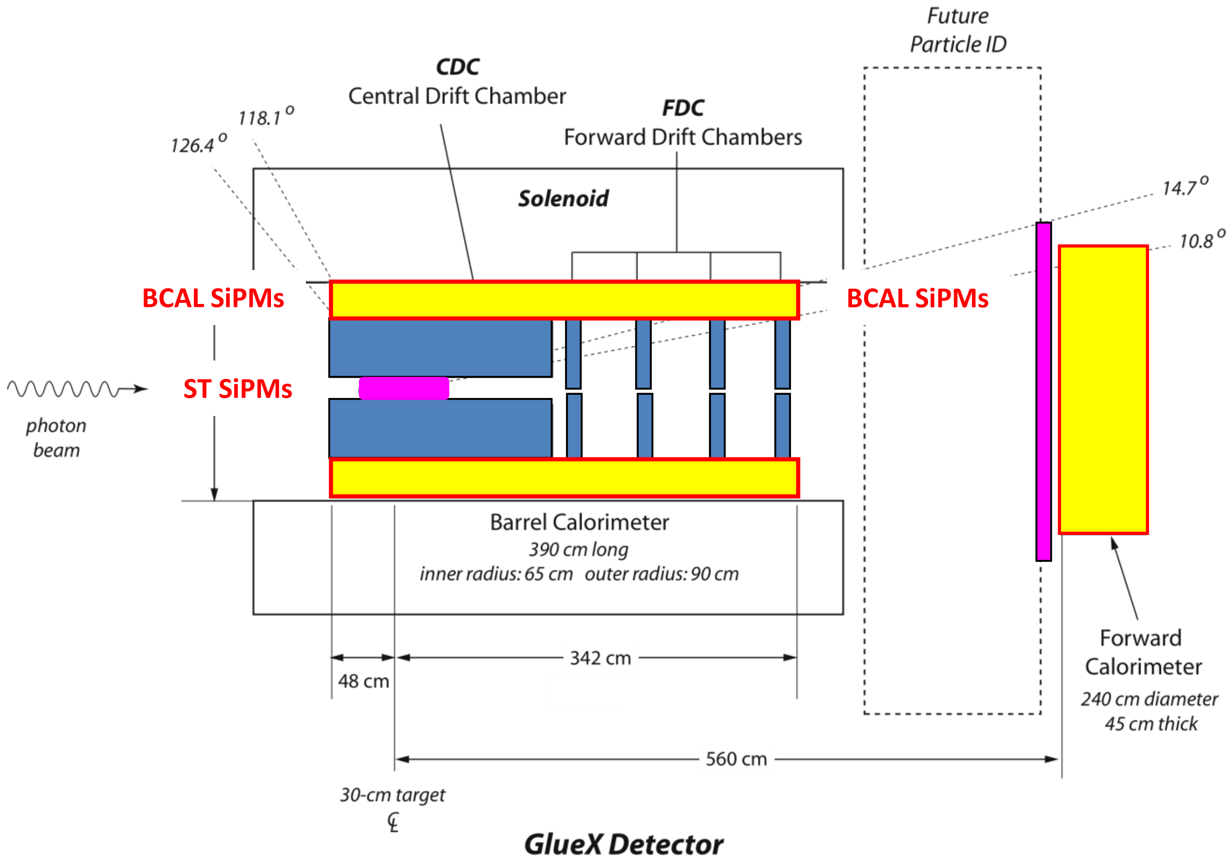
- 3 mm x 3 mm SiPMs (120 sensors)
- each ST paddle is instrumented with 4 sensors
- Measure similar dependence of the dark rate on the neutron radiation as for the BCAL sensor
- scintillator detector, not very sensitive to the dark current. Large readout thresholds can be set

  - signal pulse amplitude > 100 pixels

  - single pixel dark rate: 900 kHz per SiPM at room temperature (number of noise pixels in 100 ns time window - 0.4, pulse width – 40 ns)

- Increase of the dark rate by a factor of 10 is not a problem

Silicon Photomutipliers in Hall D



Barrel Calorimeter SiPMs (4 x 4 array of 3 mm x 3 mm)

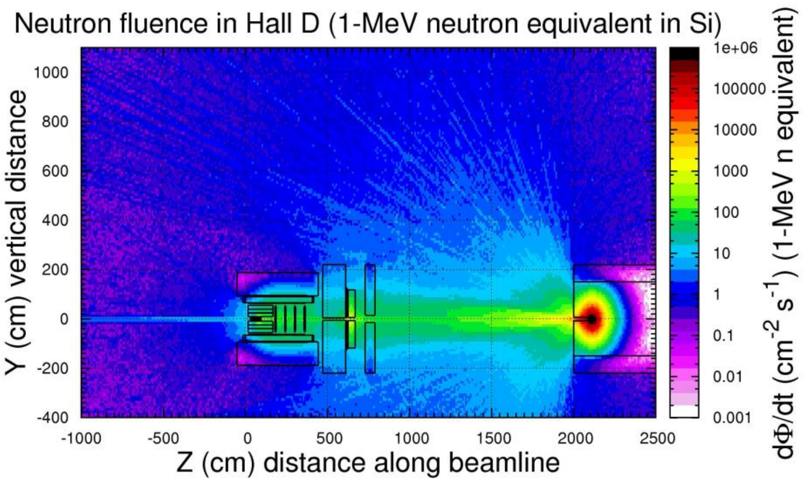
Start Counter SiPMs (3 mm x 3 mm)

Simulation of the Radiation Level in Hall D

JLAB-TN-11-005
GlueX-doc-1660
Version 0.3
February 23, 2011

Calculation of Radiation Damage to Silicon Photomultipliers in GlueX Experiment

P. Degtiarenko, A. Fassò, G. Kharashvili, A. Somov



- Estimated background from liquid hydrogen, helium, and deuterium targets using Fluka and Geant simulations provided by the JLab Radiation Control group

Neutron Background Induced by LH and LHe Targets

FLUKA, Liquid Hydrogen target

Position of control volume	n	p	π	e^-	e^+	Total
Start Counter	20.9	1.4	18.4	0.1	0.1	40.9 ± 3.1
BCAL upstream SiPM	2.0	0.1	0.3	0.0	0.0	2.4 ± 0.2
BCAL downstream SiPM	18.2	1.7	1.8	1.1	0.3	23.2 ± 0.6
75 cm downstream from BCAL	16.7	2.2	2.3	18.2	5.6	45.1 ± 1.0

GEANT, Liquid Hydrogen target

75 cm downstream from BCAL	30.5					

FLUKA, Liquid Helium target

Start Counter	112.1	34.8	14.7	0.2	0.1	162.9 ± 5.9
BCAL upstream SiPM	8.0	0.2	0.3	0.04	0.03	8.6 ± 2.2
BCAL downstream SiPM	23.0	2.1	2.2	1.0	0.3	28.7 ± 0.3
75 cm downstream from BCAL	21.1	2.7	2.5	20.1	6.8	53.7 ± 0.9

Table 1: 1-MeV neutron equivalent fluence in units of $n_{eq} \cdot s^{-1} \cdot cm^{-2}$ estimated with FLUKA and GEANT simulations. The fluences were computed in the Start Counter and BCAL SiPM regions. See definitions of the regions in the text.

Background was evaluated for the GlueX designed luminosity

In the BCAL, background is larger In the downstream end

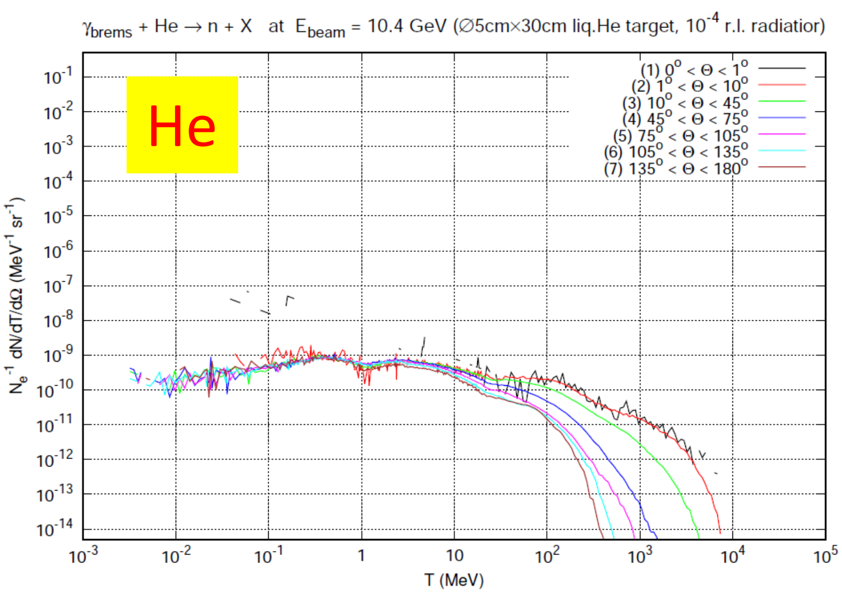
- it increases by about 30 % for the LHe target

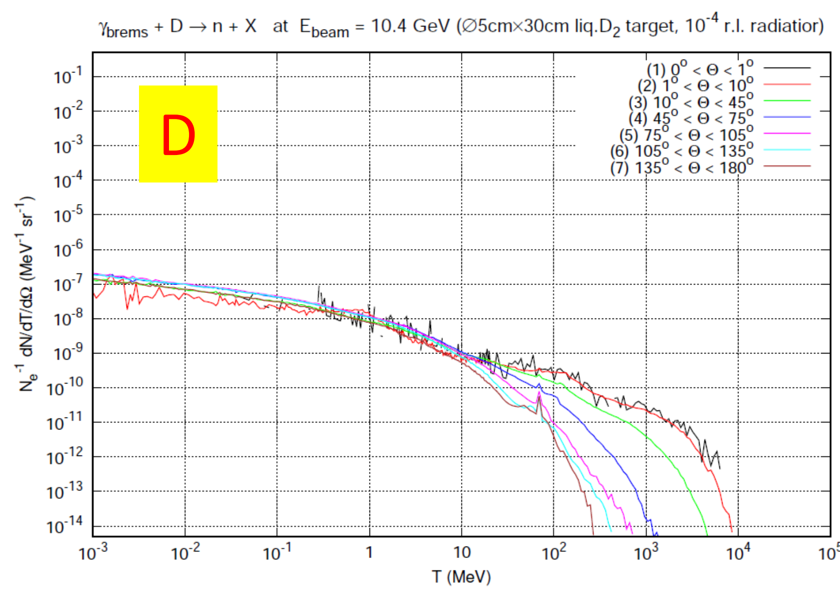
Background is significantly larger in the Start Counter SiPM region

- SRC/CT beam flux on target is 5 times smaller than that for GlueX
- Background induced by the LHe target will not exceed the GlueX level

Neutron Flux: Liquid He and D Targets

- Neutron flux originated from LHe and LD targets



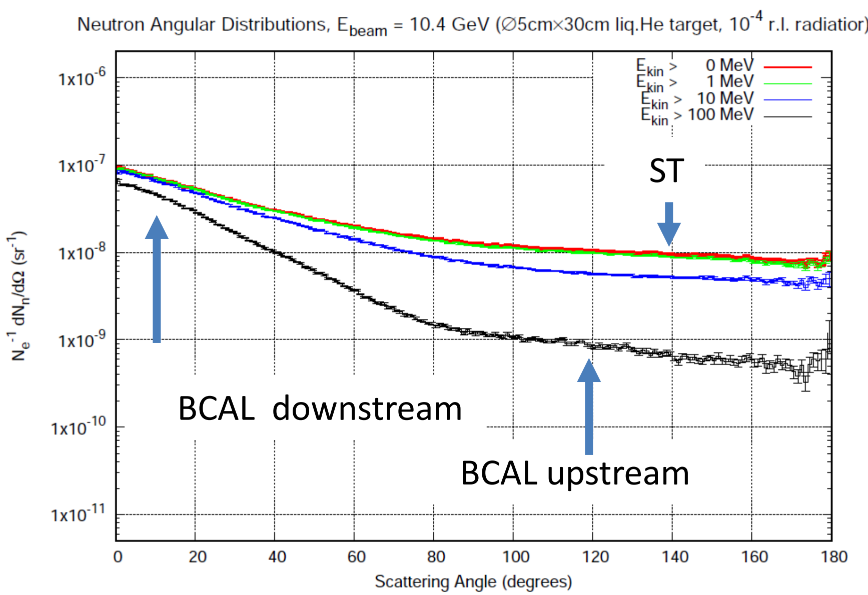


- Recent calculations by Pavel Degtyarenko

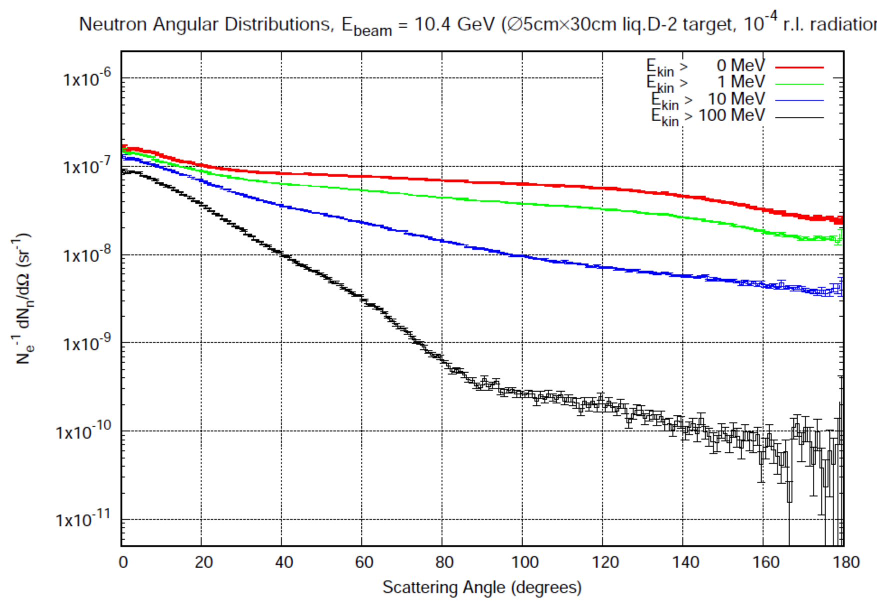
- Computed using RadCon Geant and Fluka
  - relatively good agreement between Geant and Fluka

Neutron Flux: Liquid He and D Targets

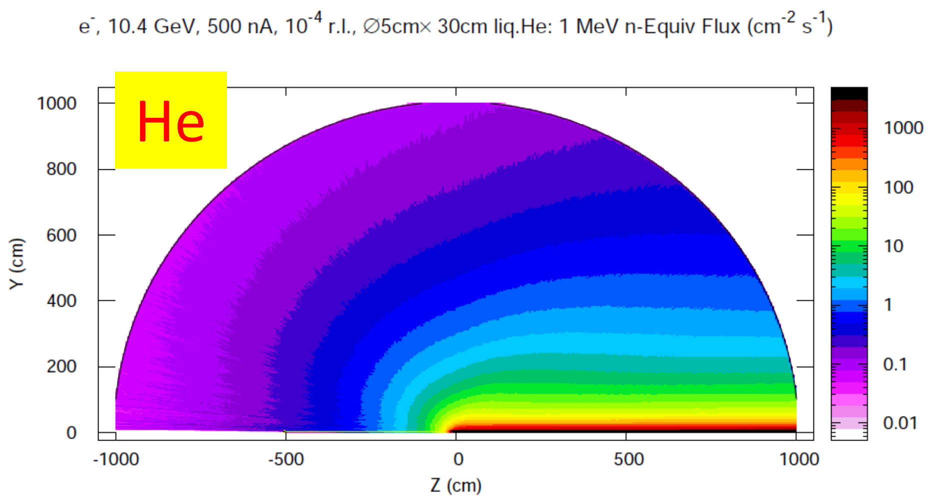
Helium

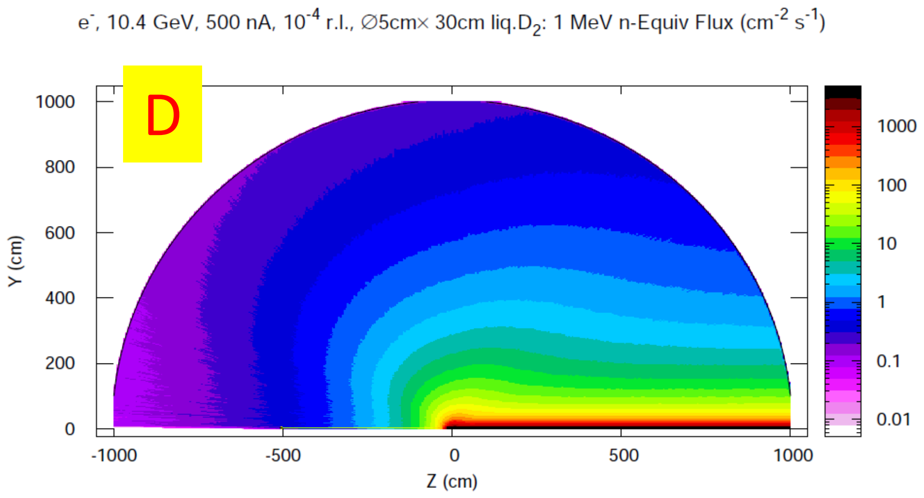


Deuterium



1 MeV Equivalent Flux: He and D Targets





- 1 MeV neutron equivalent fluence for the Deuterium target is larger than that for the He target by about a factor of
  - 3 – 4 for the ST SiPM region
  - 2 for the BCAL upstream SiPM region

Summary: Radiation Damage to SiPM

Expected life time of SiPMs

	GlueX Design	SRC/CT	
	LH target	LHe_4 target	LD target
BCAL	8 years	25 years	7.7 years
ST	5 years	6.2 years	1.6 years
SRC/CT run time		1x3 = 3 days	4.5x3 = 13.5 days

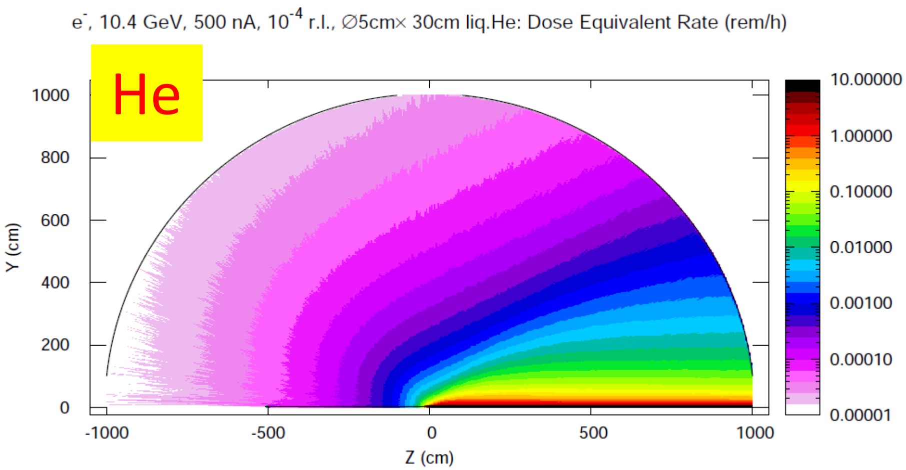
- Estimate life time using radiation doses estimated RadCon
- Conservative assumptions regarding neutron background induced by deuterium target
- Assume experiment operation efficiency of 33 %

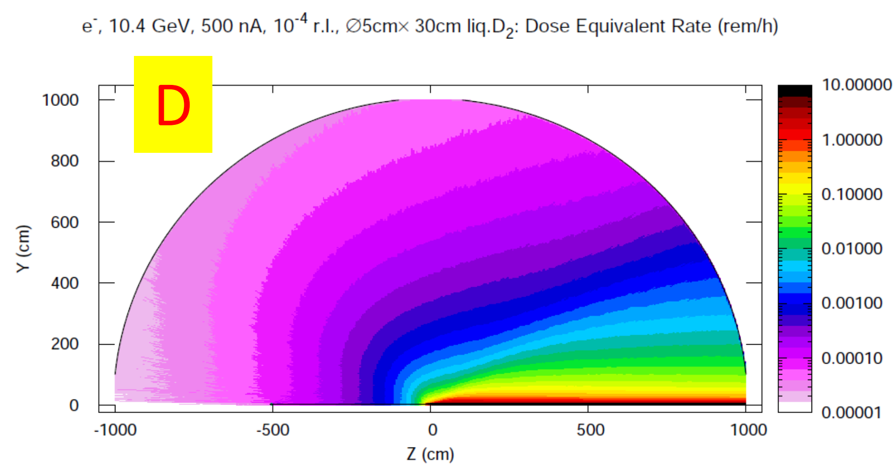
Monitoring SiPM Dark Current

- Reference to PrimEx (2.8 times smaller flux, 20 PAC days on He)
- Monitor FADC 250 pedestal width. Pedestal broadening due to the increase of the dark rate.
- No significant increase of the pedestal width observed after taking data (< 10 % with large systematic uncertainties)
- We will periodically monitor pedestal width during the SRC/CT run (special 10 min runs with the random trigger).

Radiation Level in Hall D

Dose Equivalent Rate: He and D Targets





- Estimated neutron dose equivalent rate in Hall D(ceiling) induced by the deuterium target is expected to be 3 – 4 times larger than that for helium (conservative assumption)

Radiation Level in Hall D

- Experimental Hall D was designed to handle the photon flux about 5 tames larger than the GlueX nominal flux (corresponding to 108 γ /sec in the energy range between 8.4 GeV and 9.1 GeV)
- The SRC/CT experiment will run at 5 times smaller photon flux
- The largest neutron background is expected to be produced on the deuterium target. This background was estimated to be on the level of the designed GlueX
- Background in the experimental Hall will be monitored by RadCon for each target type

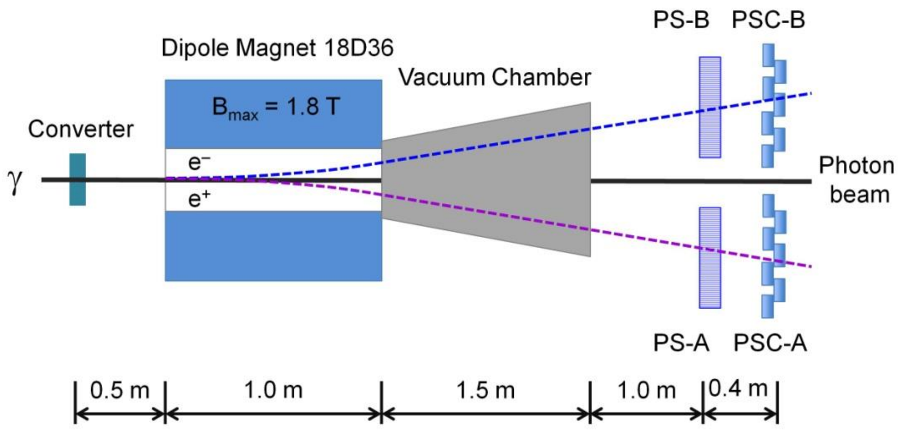
Monitoring Radiation Level in Hall D

- Installed quick access ionization chambers (show locations)
- Install thermoluminescent dosimeters (**TLD)** close to the target
- Install **Bonner spheres** (determine the energy spectrum of neutons) close to the target (coordinate with RadCon group)

Radiation Level Summary

Backup Slides

Photon Flux Measurements with Pair Spectrometer

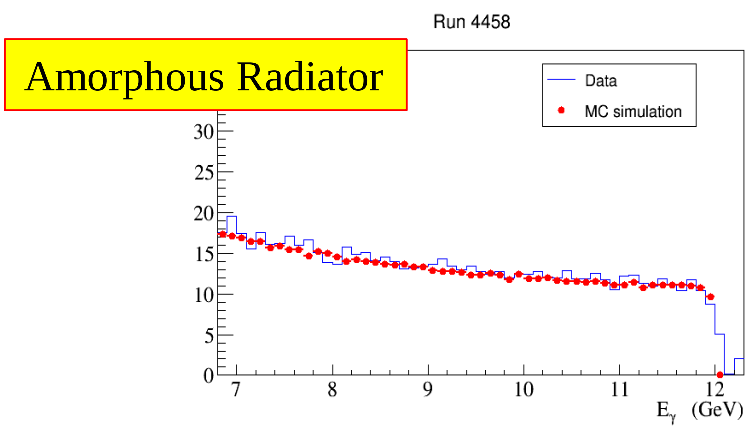


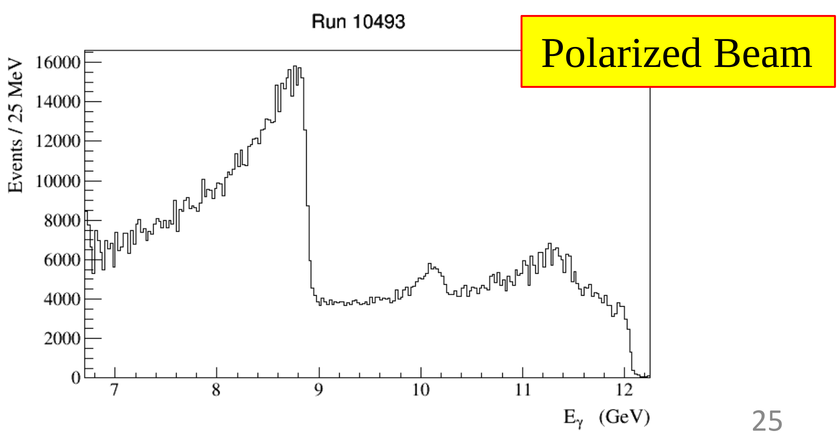
Two layers of scintillator detectors:

High-granularity hodoscope (measure photon energy in the range 6 – 12 GeV)

Low-granularity counters (use in trigger)

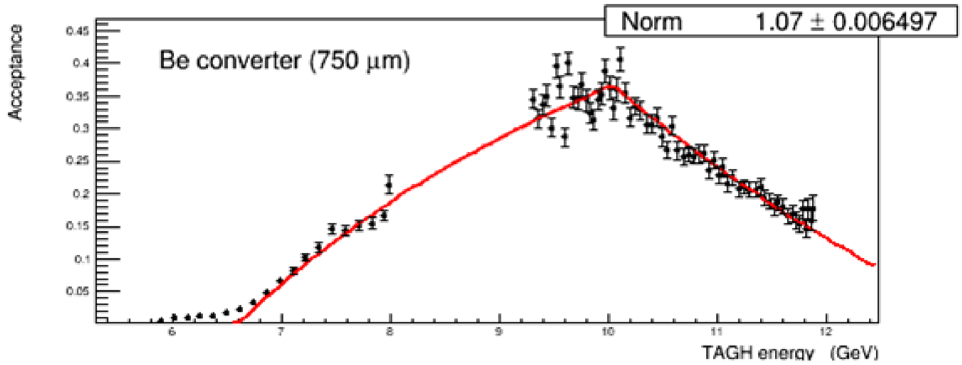
- Reconstruct the energy of a beam photon by detecting $e^{\pm}$ pairs
  - measure the photon beam flux and spectrum of the collimated photon beam





Photon Flux Measurements with Pair Spectrometer

- PS acceptance and energy determination
  - Ray tracing (measure magnetic field map)
  - Calibrate using total-absorption-counters (TAC) at low luminosity



- 3.4 mm collimator ,
2 ·10^{-5} X_0 radiator,
2 nA beam current

Calibration is performed regularly; takes 2-6 hours
- will be performed during PrimEx-D run (Recommendation 1.5)

- Special trigger type – continuous flux monitor (typical rate 1 – 3 kHz)
  - fadc / CTP scalers inserted to the data stream and EPICS

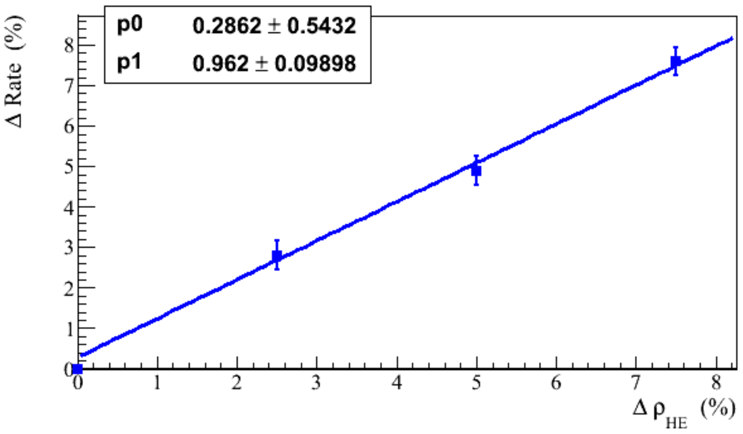
Monitor the photon flux with the precision < 1 %

Target Density Monitor

- Short term stability control:

  - photon beam flux provided by the PS
  - rates in the Start Counter (ST) and Time-of-Fight (TOF) wall

ST rate dependence on the target density



ST consists of 30 paddles surrounding the target

ST rate for production runs: 250 kHz / paddle

Coincidence of hits between the ST and TOF
(2 x 2 bars in TOF at R = 30 cm & one ST paddle)
1.5 kHz

- Long term stability control:

  - monitor using Compton process; expected rate in the photon range of interest is about 30 Hz

Pair Spectrometer Acceptance Calibration

- Calibrate PS acceptance using total-absorption counter (TAC)

- Data samples were acquired for three converters

  - 5.7×10^{-3} R.L. Al (508 μm foil)
  - 2.1×10^{-3} R.L. Be (750 μm foil)
  - 0.21×10^{-3} R.L. Be (75 μm foil)

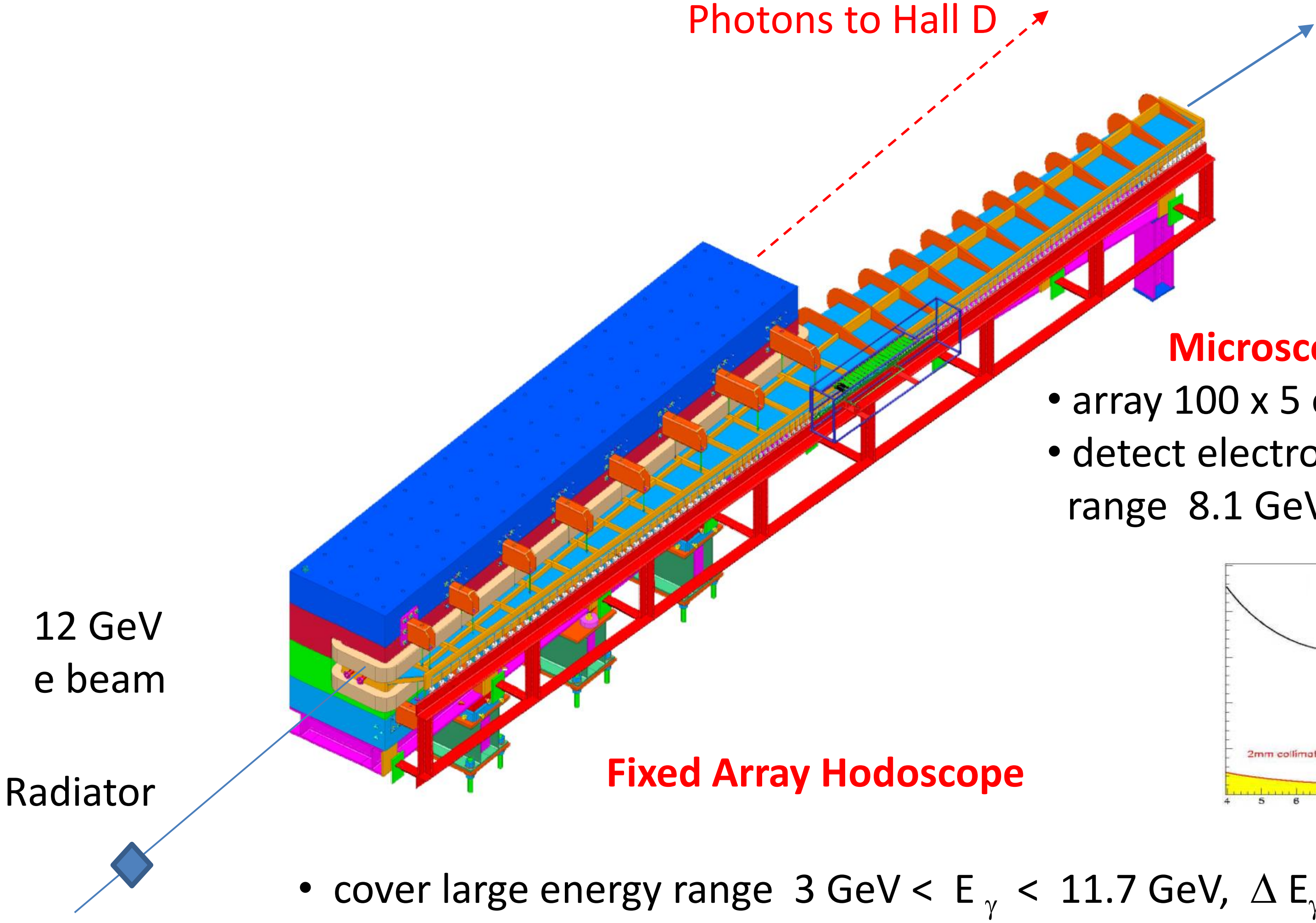
- Run conditions

  - 3.4 mm collimator , $2 \cdot 10^{-5}$ radiator, 2 nA beam current

- Trigger

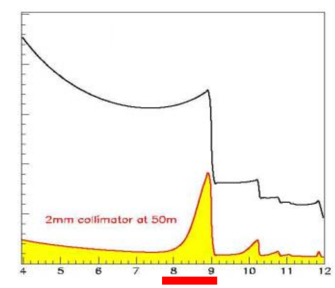
  - run two triggers in parallel: PS and TAC (energy sum)
  - PS rate: 10 Hz 750 μm Be
  - TAC rate: 200 – 300 kHz (trigger prescaling factor 129)

Tagged Photon Beam



Microscope

- array 100 x 5 of thin scintillators
- detect electrons in the energy range 8.1 GeV < E_γ < 9.2 GeV



- cover large energy range 3 GeV < E_γ < 11.7 GeV, $\Delta E_\gamma / E_\gamma < 0.002$
- 233 counters installed
- detect tagged ellectrons with E_γ > 9.2 GeV during data runs
- accidental background for PrimEx-D < 4 %