

# *Beamline Commissioning and Radiation Level*

A. Somov, Jefferson Lab

E12-19-003

Experiment Readiness Review

May 7, 2020

# Outline

- Beam Commissioning (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 $\gamma/\text{sec}$	Flux on target (0.012 – 11.7 GeV) $\gamma/\text{sec}$
GlueX Design	8.4 - 9.1	40 %	$10^8$	$1.8 \cdot 10^9$
GlueX II	8.4 - 9.1	40 %	$5 \cdot 10^7$	$9 \cdot 10^8$
<b>This experiment</b>	<b>8.4 - 9.1</b>	<b>40 %</b>	<b><math>2 \cdot 10^7</math></b>	<b><math>3.6 \cdot 10^8</math></b>

## *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:

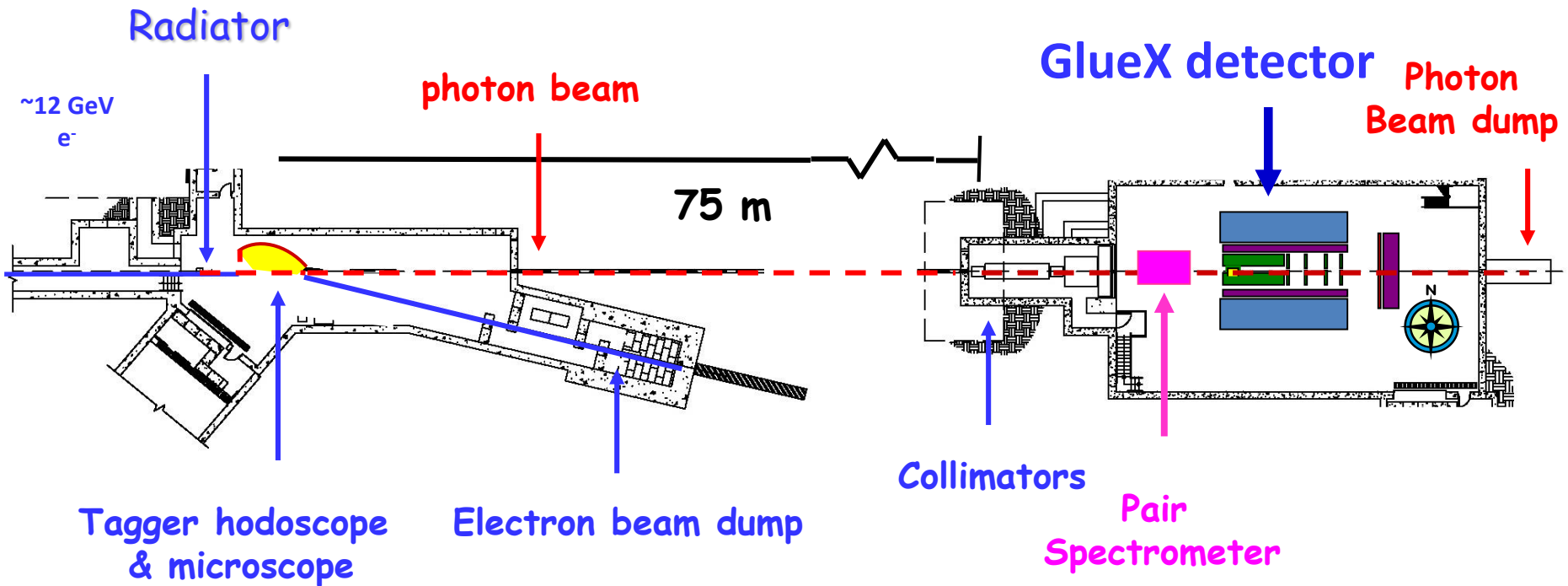
5 mm

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

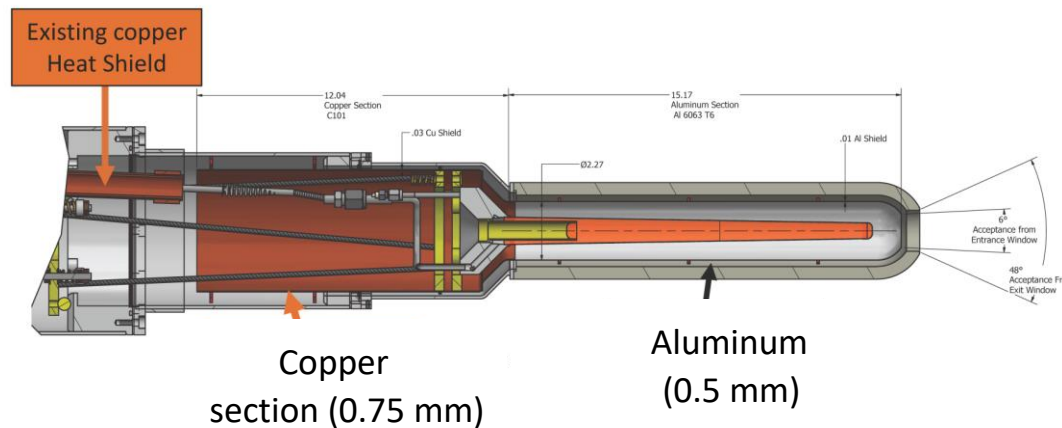
Use standard Hall D beam line equipment for SRC / CT !



# Targets

See C. Keith talk

- LD ( $\text{LHe}_4$ ) target. Standard GlueX target cell and cryogenic system
  - $\text{LHe}_4$  target was used in the Hall D PrimEx experiment



- 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

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

# SRC Targets and Run Period

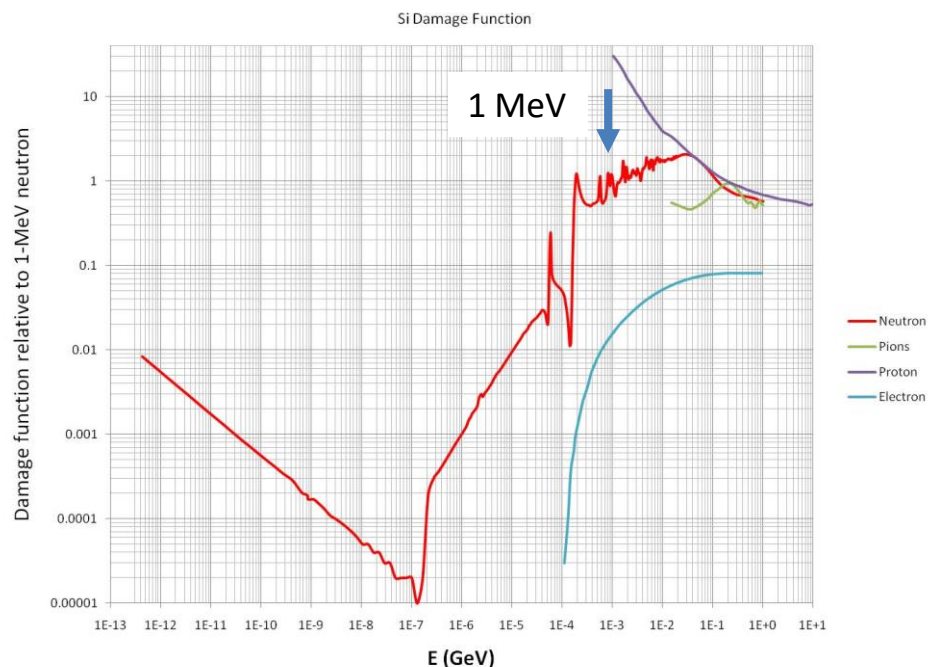
Target	Thickness			Atoms/cm <sup>2</sup>	Run Time (days)
	cm	g/cm <sup>2</sup>	%X <sub>0</sub>		
LH	30	2.1	3.4	1.28·10 <sup>24</sup>	GlueX
D	30	4.9	4.1	1.51·10 <sup>24</sup>	4.5
<sup>4</sup> He	30	3.5	4.0	5.68·10 <sup>23</sup>	1
<sup>12</sup> C	1.5	3	7	1.45·10 <sup>23</sup>	7

- 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  $E_{kin} \geq 1 \text{ MeV}$

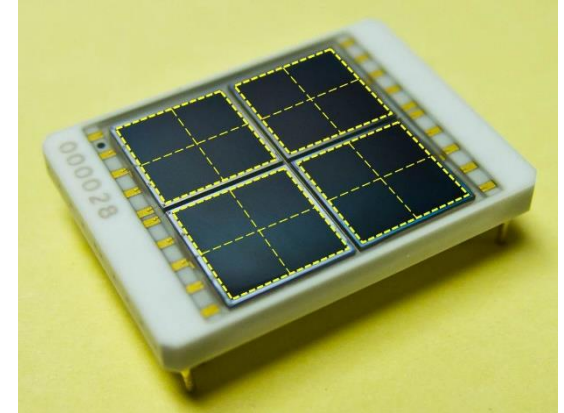


**Increase of the SiPM dark current**

# Silicon Photomultipliers 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
  - dark current decreases by about a factor of 3 when SiPMs are cooled to 5° C
- radiation hardness studied using Am-Be neutron source and beam test setup in Hall A



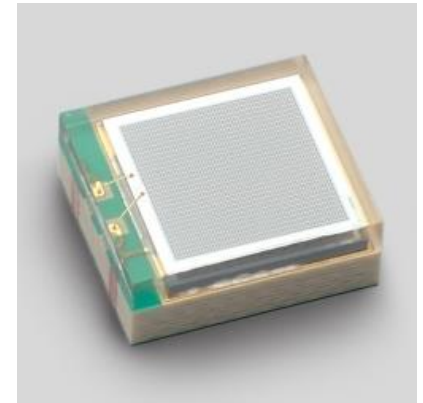
- [https://halldweb.jlab.org/wiki/index.php/SiPM\\_Radiation\\_Hardness\\_Tests](https://halldweb.jlab.org/wiki/index.php/SiPM_Radiation_Hardness_Tests)
- Radiation hardness test of BCAL SiPMs, NIM A **698** (2013) 234
- Radiation tolerance survey, Proceedings of IEEE2012 conference
- dark current is doubled after irradiating SiPMs with the equivalent fluence of about  $10^8 n_{EQ} / \text{cm}^2$  (critical dose about 32 rem, dark current increase by x5 )
- expected lifetime at GlueX designed luminosity ( $10^8 \gamma / \text{sec}$ )
  - 5 years for Hydrogen
  - 3.2 years for Helium

(assuming the experiment operation efficiency of 33%)

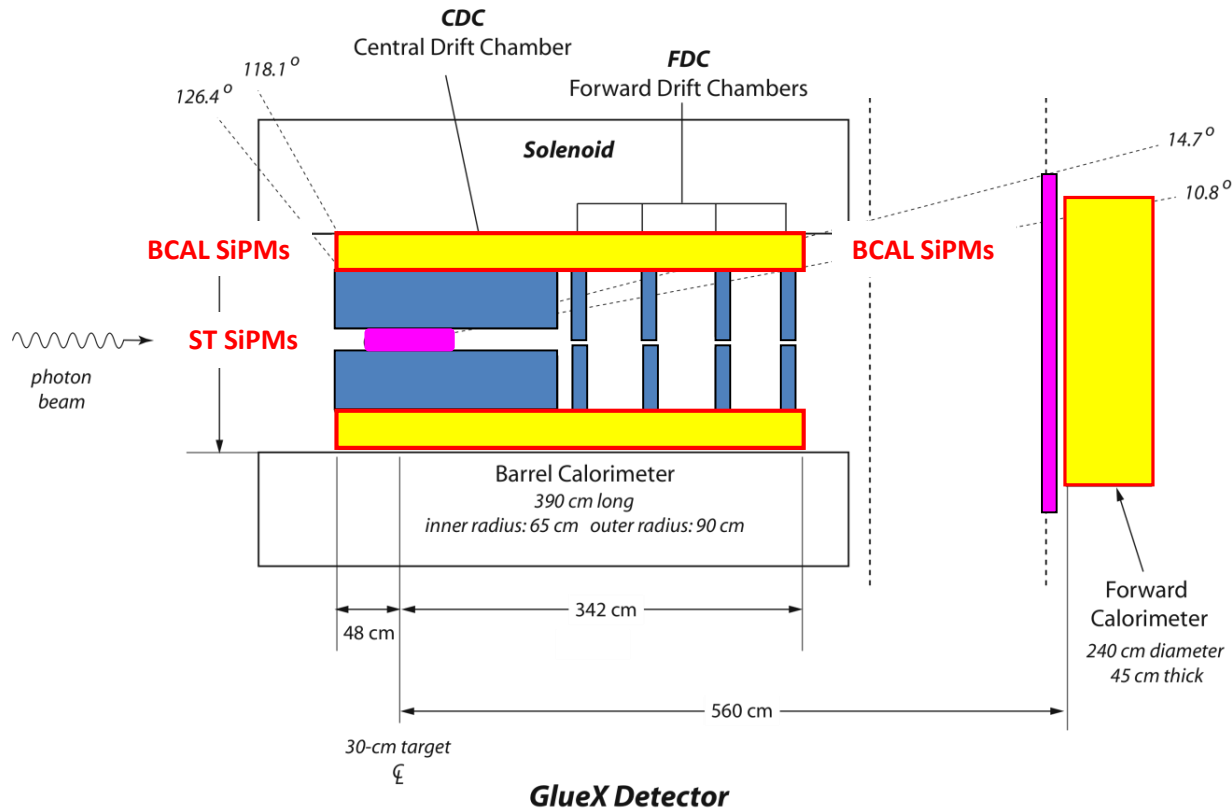
# Silicon Photomultipliers in Hall D

## 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 Photomultipliers in Hall D



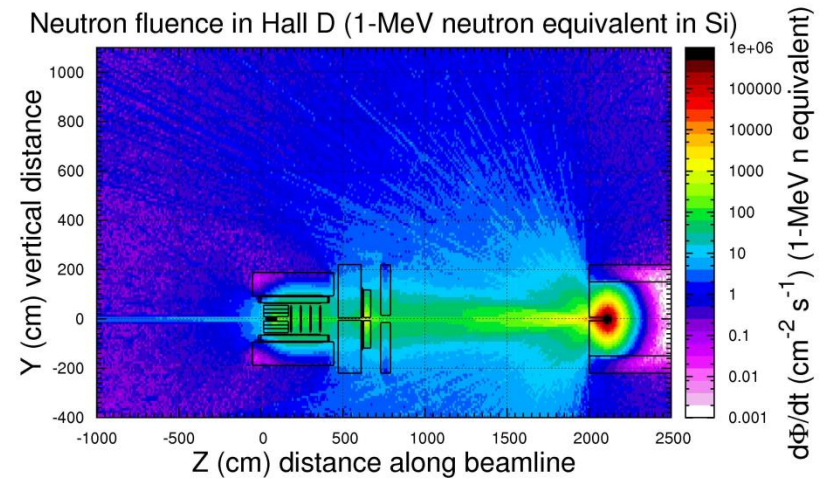
- Barrel Calorimeter SiPMs ( 4 x 4 array of 3 mm x 3 mm)
- Start Counter SiPMs ( 3 mm x 3 mm )

# 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	$\pi$	$e^-$	$e^+$	Total
Start Counter	20.9	1.4	18.4	0.1	0.1	$40.9 \pm 3.1$
BCAL upstream SiPM	2.0	0.1	0.3	0.0	0.0	$2.4 \pm 0.2$
BCAL downstream SiPM	18.2	1.7	1.8	1.1	0.3	$23.2 \pm 0.6$
75 cm downstream from BCAL	16.7	2.2	2.3	18.2	5.6	$45.1 \pm 1.0$

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	$162.9 \pm 5.9$
BCAL upstream SiPM	8.0	0.2	0.3	0.04	0.03	$8.6 \pm 2.2$
BCAL downstream SiPM	23.0	2.1	2.2	1.0	0.3	$28.7 \pm 0.3$
75 cm downstream from BCAL	21.1	2.7	2.5	20.1	6.8	$53.7 \pm 0.9$

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

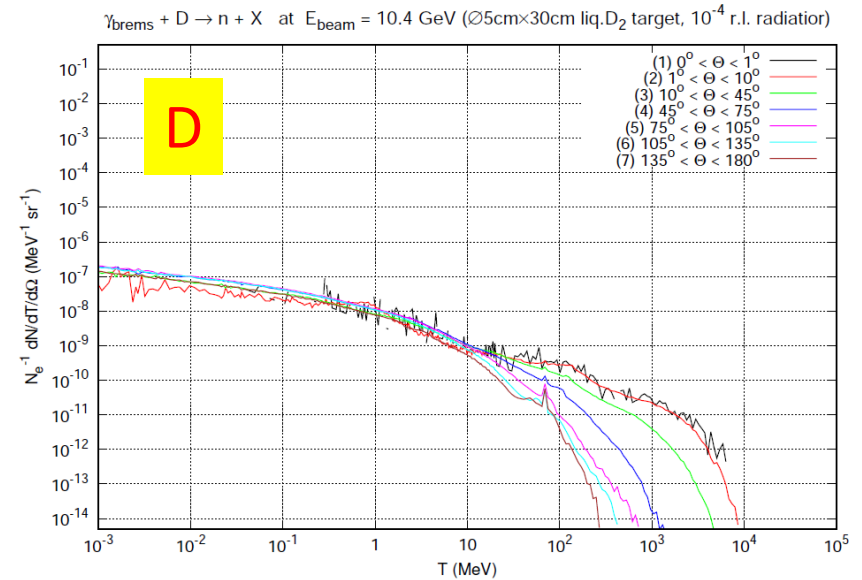
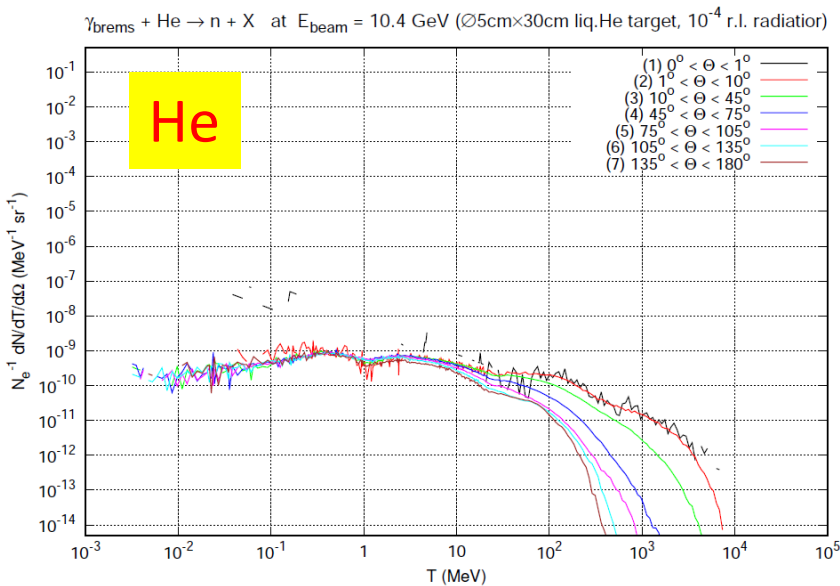
- it increases by about 30 % for the LHe target

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

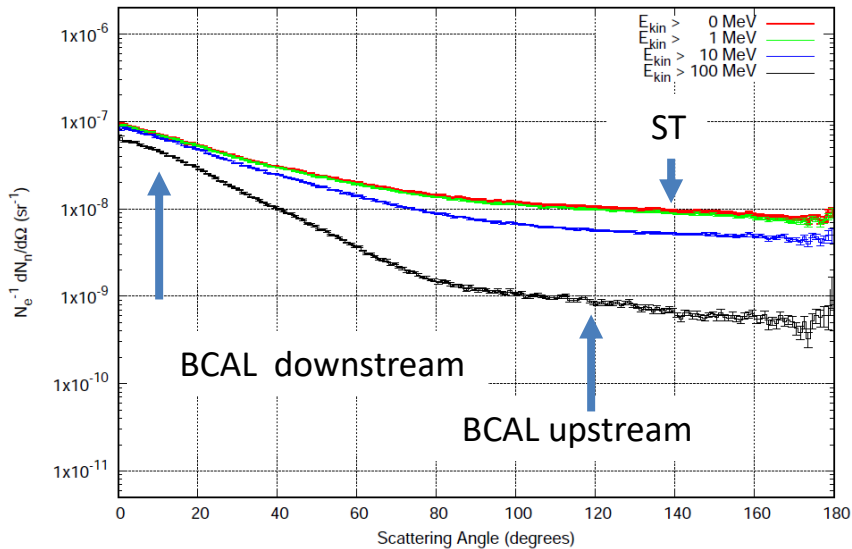
# Neutron Flux: Liquid He and D Targets

- Neutron angular distributions, FLUKA simulation

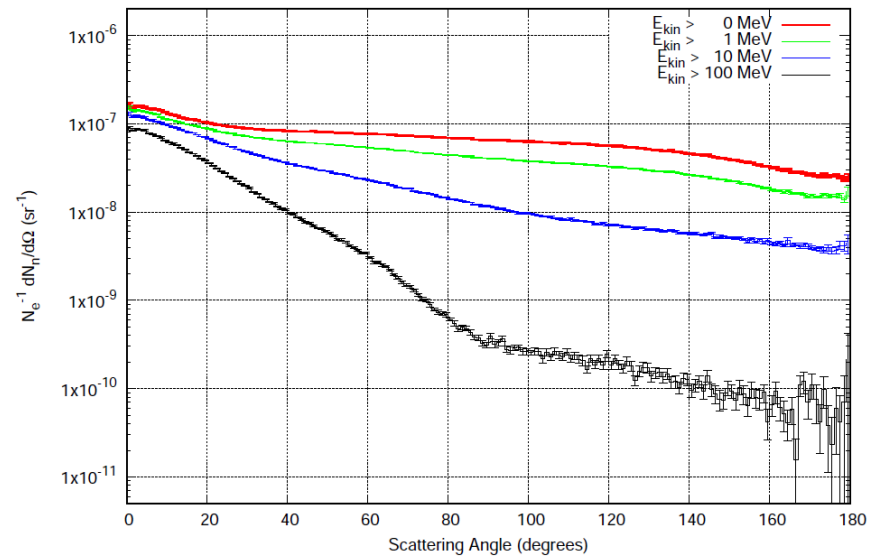
Helium

Deuterium

Neutron Angular Distributions,  $E_{\text{beam}} = 10.4 \text{ GeV}$  ( $\varnothing 5\text{cm} \times 30\text{cm}$  liq.He target,  $10^{-4}$  r.l. radiator)



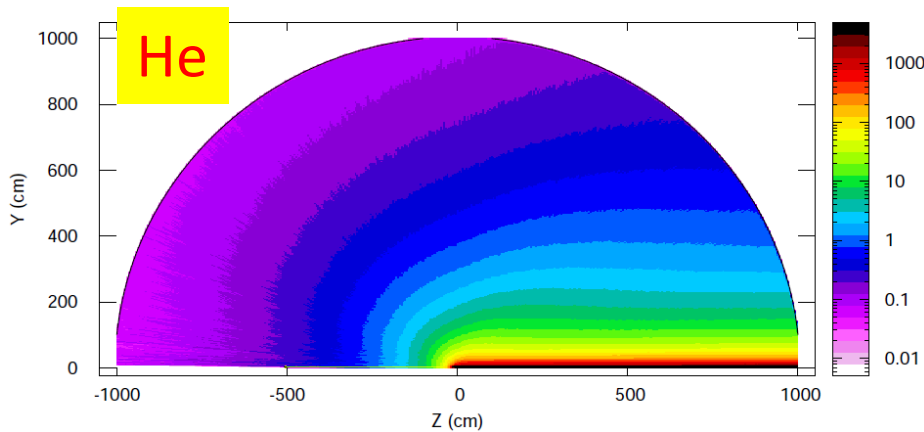
Neutron Angular Distributions,  $E_{\text{beam}} = 10.4 \text{ GeV}$  ( $\varnothing 5\text{cm} \times 30\text{cm}$  liq.D-2 target,  $10^{-4}$  r.l. radiator)



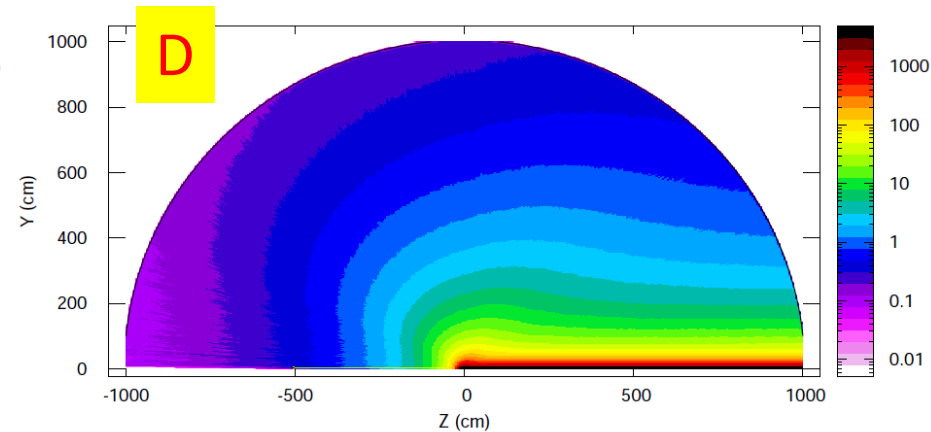


# 1 MeV Equivalent Flux: He and D Targets

$e^-$ , 10.4 GeV, 500 nA,  $10^{-4}$  r.l.,  $\varnothing 5\text{cm} \times 30\text{cm}$  liq.He: 1 MeV n-Equiv Flux ( $\text{cm}^{-2} \text{s}^{-1}$ )



$e^-$ , 10.4 GeV, 500 nA,  $10^{-4}$  r.l.,  $\varnothing 5\text{cm} \times 30\text{cm}$  liq.D<sub>2</sub>: 1 MeV n-Equiv Flux ( $\text{cm}^{-2} \text{s}^{-1}$ )



- 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 Start Counter and BCAL downstream regions
  - 2 for the BCAL upstream SiPM region

# Summary: Radiation Damage to SiPM

Expected life time of SiPMs

	GlueX Design	SRC/CT	
	LH target	LHe <sub>4</sub> target	LD target
BCAL	5 years	19.9 years	6.5 years
ST	2.1 years	2.6 years	245 days

SRC/CT run time

1x3 = 3 days

4.5x3 = 13.5 days

- Estimate life time using radiation doses computed by RadCon
- Conservative assumptions regarding neutron background induced by deuterium target
- Assume experiment operation efficiency of 33 %
- Degradation of the ST SiPMs after the run with deuterium target is equivalent to taking data in the GlueX experiment for about 1.4 months

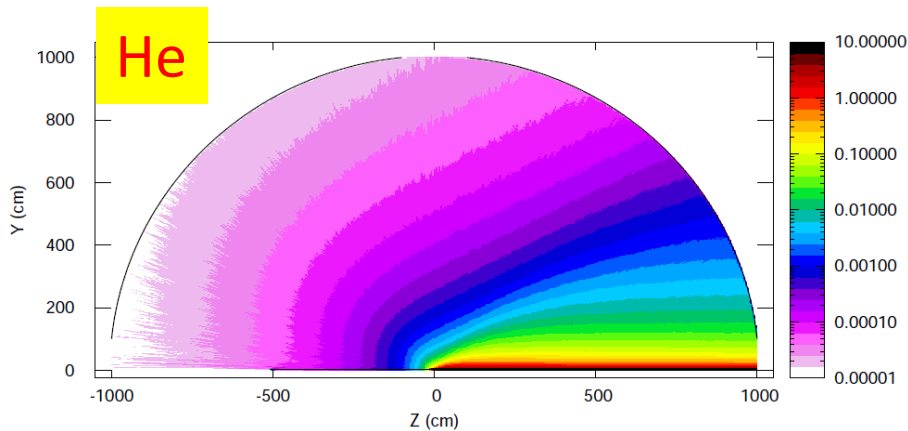
# Monitoring SiPM Dark Current

- We are planning to monitor the dark rate of the Start Counter SiPMs during the SRC/CT experiment
  - special 10 min runs with the random trigger and unsparcified readout of fadc250
  - measure pedestal broadening due to the increase of the dark rate
- Checked pedestals for ST during PrimEx run (20 PAC days on He4 target, 2.8 times smaller photon flux than in our experiment)
  - no significant increase of the pedestal width observed after taking data ( < 10 %, on the level of systematic uncertainties)

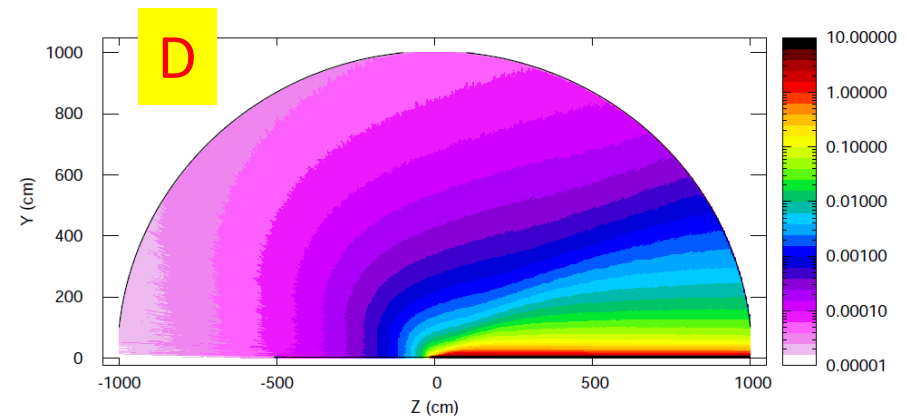
# Radiation Level in Hall D

## Dose Equivalent Rate: He and D Targets

$e^-$ , 10.4 GeV, 500 nA,  $10^{-4}$  r.l.,  $\varnothing 5\text{cm} \times 30\text{cm}$  liq.He: Dose Equivalent Rate (rem/h)



$e^-$ , 10.4 GeV, 500 nA,  $10^{-4}$  r.l.,  $\varnothing 5\text{cm} \times 30\text{cm}$  liq.D<sub>2</sub>: Dose Equivalent Rate (rem/h)



- Estimated neutron dose equivalent rate in Hall D(ceiling) produced in 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 2 times larger than the GlueX nominal flux (corresponding to  $10^8 \gamma / \text{sec}$  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

# 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 neutrons) close to the target (coordinate with RadCon group)

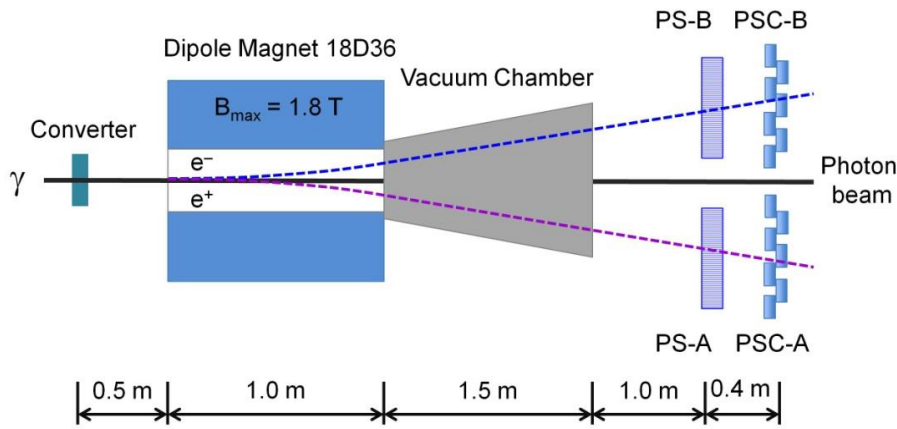
# Radiation Level Summary

- The SRC/CT experiment will be operated at the photon flux 5 times smaller than that of the designed GlueX experiment
- Neutron background was estimated using Fluka and Geant simulations provided by the RadCon group
- Degradation of the SiPM performance due to the neutron radiation, the dark rate increase, is expected to be small even for the deuterium target (for the ST, the degradation is equivalent to running GlueX for 1.4 months).
- SiPM dark current will be monitored during the SRC/CT experiment
- No local shielding is required for the SRC/CT experiment
- The radiation level in Hall D is expected not to exceed the GlueX designed level
- The background level in Hall D will be continuously monitored by the RadCon group

# **Backup Slides**



# Photon Flux Measurements with Pair Spectrometer



Two layers of scintillator detectors:

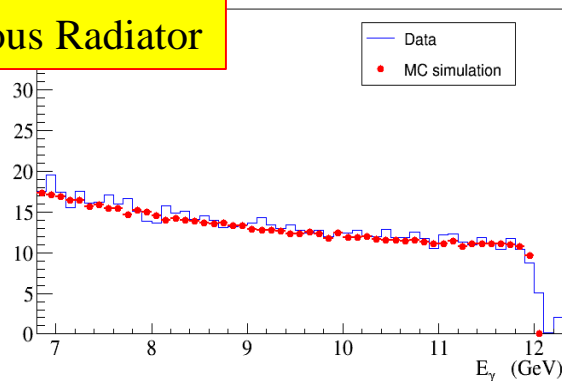
High-granularity hodoscope  
(measure photon energy in the range 6 – 12 GeV)

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

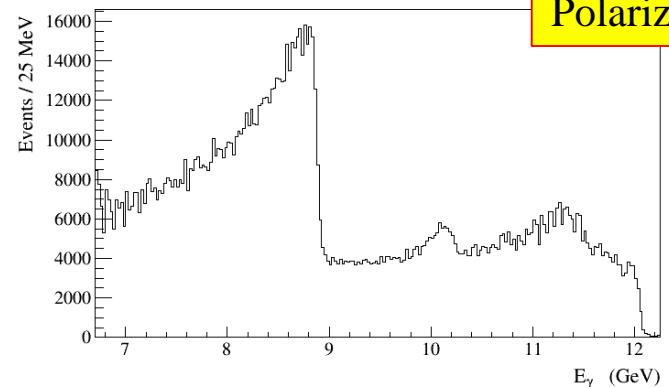
Run 4458

Amorphous Radiator

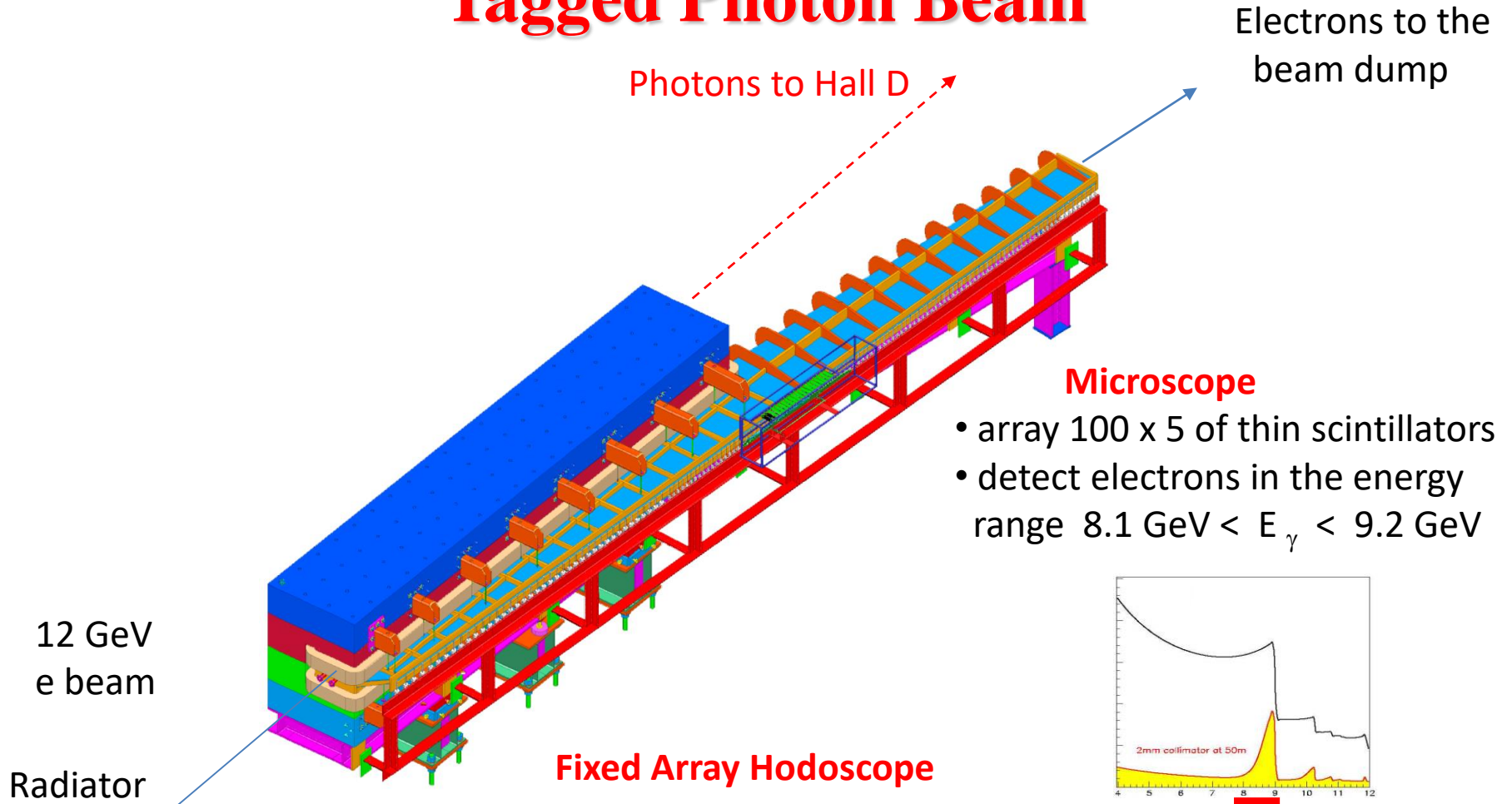


Run 10493

Polarized Beam



# Tagged Photon Beam



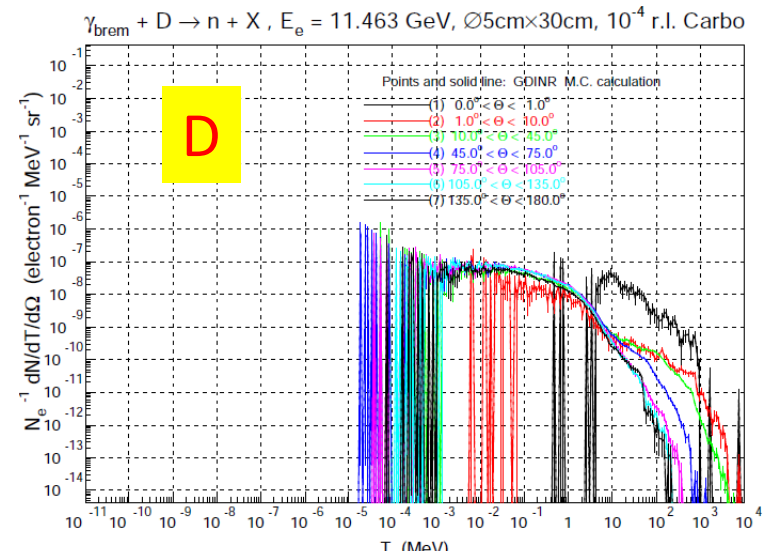
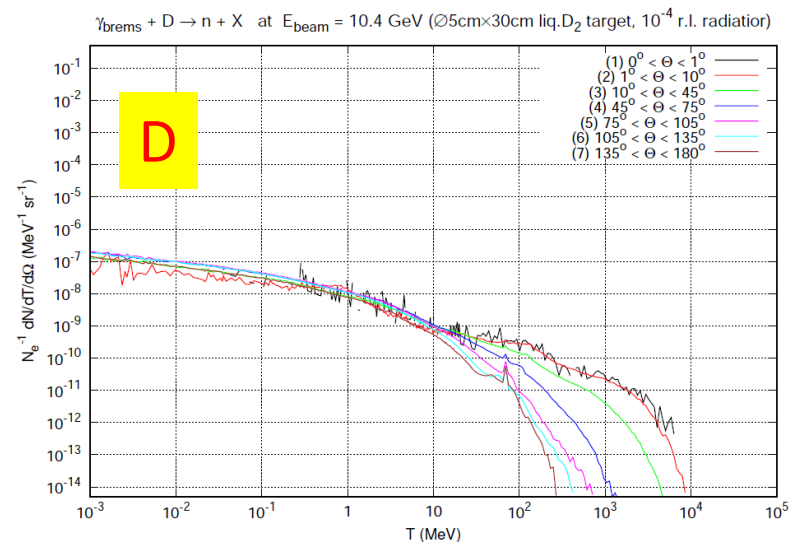
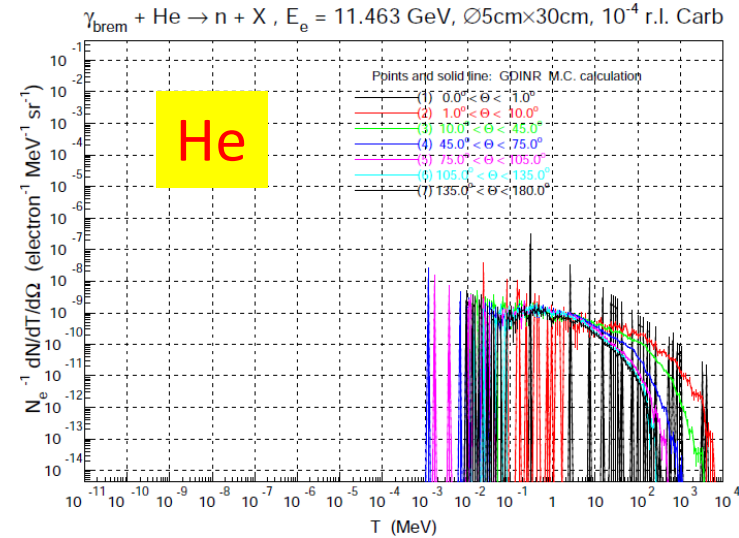
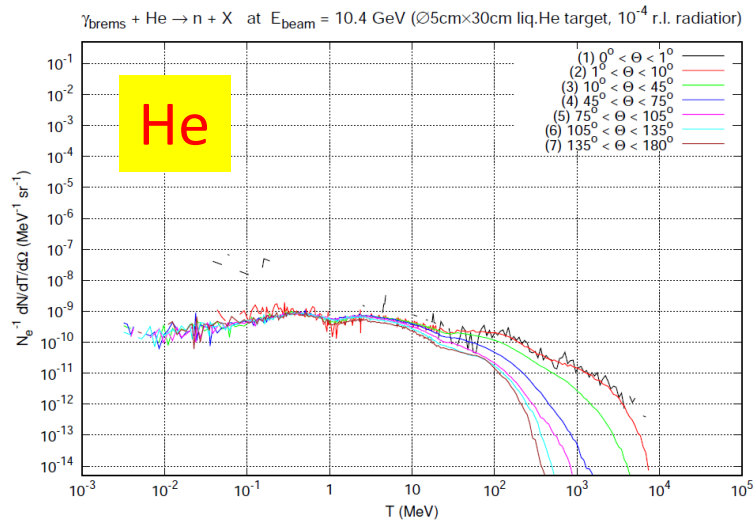
- cover large energy range  $3 \text{ GeV} < E_\gamma < 11.7 \text{ GeV}$ ,  $\Delta E_\gamma / E_\gamma < 0.002$
- 233 counters installed
- detect tagged electrons with  $E_\gamma > 9.2 \text{ GeV}$  during data runs
- **accidental background for PrimEx-D  $< 4\%$**

# Comparison between FLUKA and RadCon Geant

P. Degtiarenko

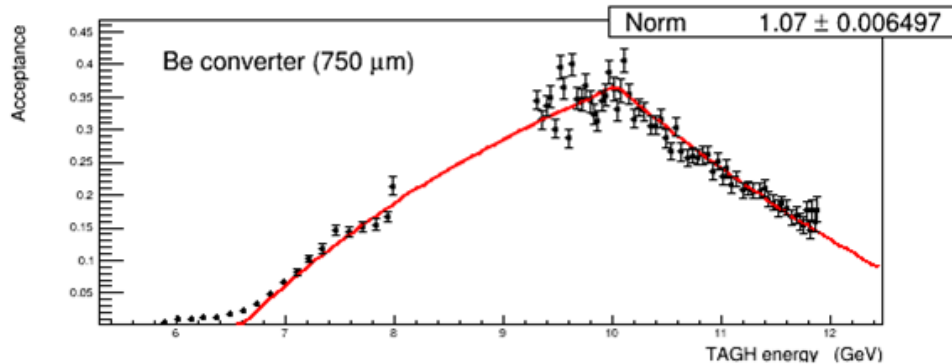
FLUKA

Geant



# 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<sup>-5</sup> X<sub>0</sub> radiator,  
2 nA beam current

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

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

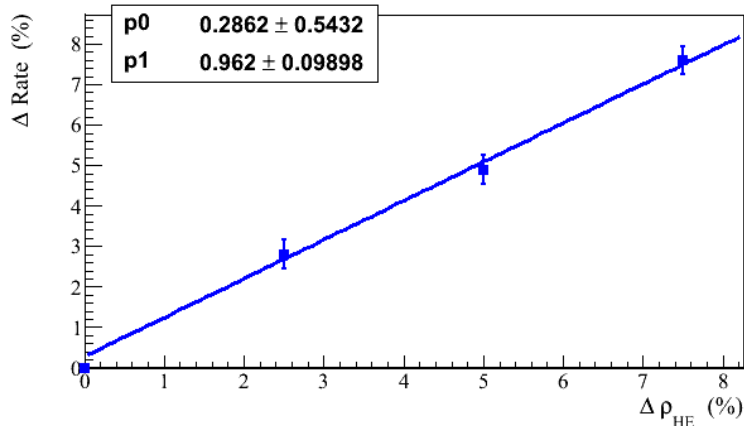
Monitor the photon flux with the precision < 1 %

# 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
  - $5.7 \times 10^{-3}$  R.L. Al (508  $\mu\text{m}$  foil)
  - $2.1 \times 10^{-3}$  R.L. Be (750  $\mu\text{m}$  foil)
  - $0.21 \times 10^{-3}$  R.L. Be (75  $\mu\text{m}$  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  $\mu\text{m}$  Be
  - TAC rate: 200 – 300 kHz ( trigger prescaling factor 129 )

# Summary: Radiation Damage to SiPM

Estimates based on the damage described in the NIM paper  
(more conservative estimates are in the main talk)

Expected life time of SiPMs

	GlueX Design	SRC/CT	
	LH target	LHe <sub>4</sub> target	LD target
BCAL	8 years	31 years	10.1 years
ST	3.1 years	3.8 years	1 years

SRC/CT run time

1x3 = 3 days

4.5x3 = 13.5 days

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