A Novel Fast Response and Radiation-resistant Scintillator Detector for Beam Loss Monitor

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Abstract

At high luminosity era, beam loss monitor(BLM) with fast response and good radiation resistance is crucial for smooth and safe operation of collider. In this poster, we report the design and test results of a fast response and radiation-resistant scintillator detector as the beam loss monitor of high intensity beam especially at low energy part such as RFQ. The detector is consistent of a 2cm x 2cm x 0.5 cm LYSO crystal readout by a 0.6 cm x 0.6 cm Silicon photomultiplier (SiPM). The detectors we constructed have been tested with various radioactive sources. Results show that the detector has good sensitivity to photon and charged particles at energy range of tens of keV to several MeV with good linearity and energy resolution (23% for 60 keV X-ray); Two detectors (one parallel to the beam and the other perpendicular to the beam) are installed outside of the vacuum chamber shell of a 800 MeV electron storage ring and tested. The details of the test and results will be introduced.

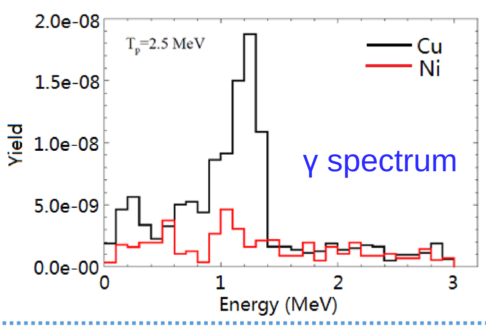
Why We Choose SiPM + LYSO Structure as BLM Detector

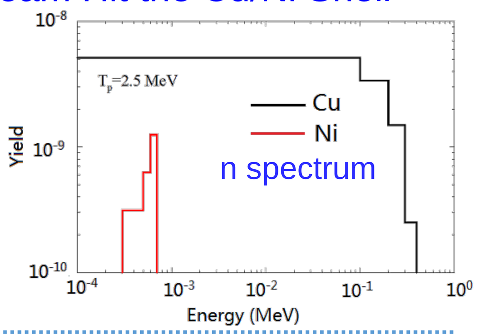
Due to high intensity of the beam, even a small amount of beam loss may cause serious damage to accelerator components. The ultimate goal of BLM system is: to identify the loss level (and the loss location and time structure)[1], to be able to protect the machine at uncontrolled loss, and if possible, to provide diagnostic information of the beam. Following requirements need to be satisfied by BLM detectors:

- ✓ *Sensitive to secondary particles;* ✓ *Fast response;* ✓ *Excellent radiation-resistances;*
- ✓ *Insensitive to magnetic field;* ✓ *Cost efficiency;*

2.5MeV Proton Beam Hit the Cu/Ni Shell[2]

For low energy (<10 MeV) but high intensity proton accelerator such as RFQ, BLM detector must be sensitive to photon, instead of electron, because of the large yield of γ-ray. as we can see from the simulation results.





Comparison to Traditional BLM Detectors

Common Beam Loss Detector	Type of Particle Detected	Sensitivity	Response Time	Radiation Hardness	Price
Scintillator +PMT	photon, (neutron,) charged particle	High	Depend on Scintillator	PS^a:1MRad LS^b :10Mrad	Expensive
PIN diodes	charged particle	Low	Fast	Good	Inexpensive
Ionization Chamber	charged particle	Medium	Slow	Good	Inexpensive
BF3 Counter Tube	neutron	Low	Slow	Good	Expensive

a: Plastic Scintillator b: Liquid Scintillator

The traditional ionization chamber, plastic (liquid) scintillator + PMT, PIN diodes etc has difficulties to satisfy all of the requirements.

A novel design of BLM detectors is proposed, using LYSO crystal scintillator coupled with SiPM.

Property	LYSO
Density (g/cm^3)	7.4
Decay time (ns)	40
Yield (ph/MeV)	30000
Radiation length (cm)	1.14
Radiation-hardness	100Mrad[3]

	SiPM	PMT
Sensitivity to Magnetic Field	~T	~10 Gs
Size	~0.2cm	~10cm
Gain	10^6	10^6
Working voltage	<100V	~1000V

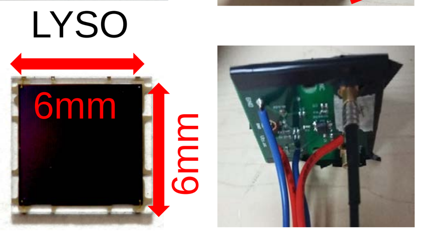
LYSO features high light yield, short decay time, relative dense and very good radiation resistance (2 orders of magnitude higher than plastic scintillator). Compared to traditional photoelectric sensor-PMT, SiPM has many advantages. It is compact, economy, insensitive to magnetic field and has low working voltage, good charge resolution and broad spectra response.

[1] Zhukov, A. Proceedings of the 2010 Beam Instrumentation Workshop. Santa Fe. Vol. 553. 2010.
[2] Craig Hogan et al., The Fermilab Holometer, 2009, Fermilab-Proposal-0990.
[3] Yang F, Zhang L, Zhu R Y. IEEE T Nucl Sci, vol. 63, pp. , 2016.

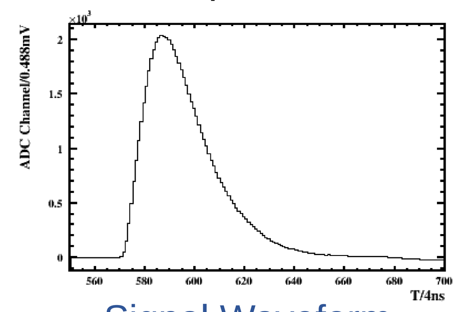
Detector Design

- *Using novel fast and radiation-resistant crystal scintillator, LYSO(2cm*2cm*0.5cm);*
- *Read out by Silicon photomultiplier (SiPM) instead of PMT;*
- *The crystal was wrapped by Tyvek, to improve scintillation photon collecting efficiency.*
- *The read out circuit was designed with a 10x preamplifier and power supply filter circuit, to obtain better electronic performance.*
- *Advantages:*
  - ✓ *Insensitive to magnetic field*
  - ✓ *Compact structure*
  - ✓ *Low noise*
  - ✓ *Fast response*

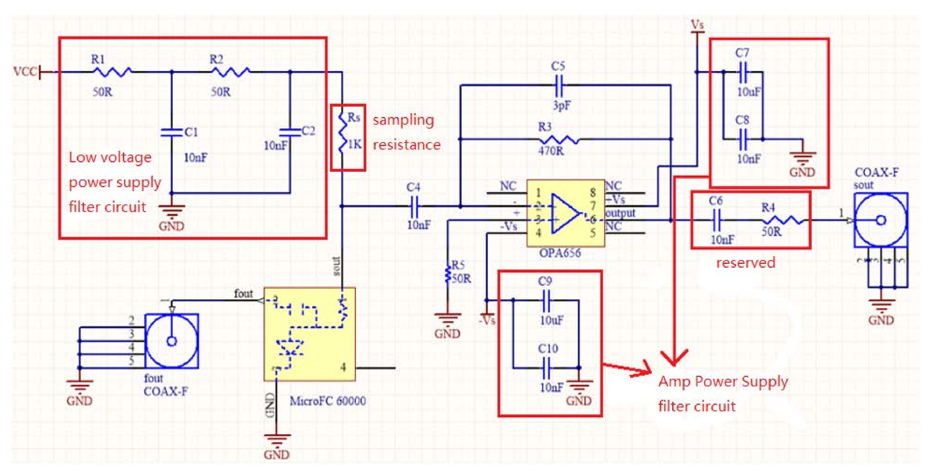
LYSO



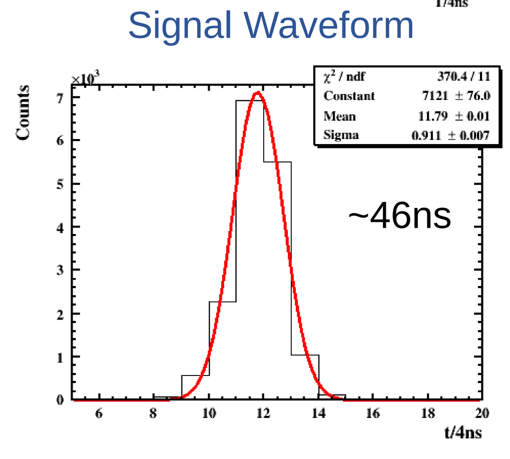
SiPM



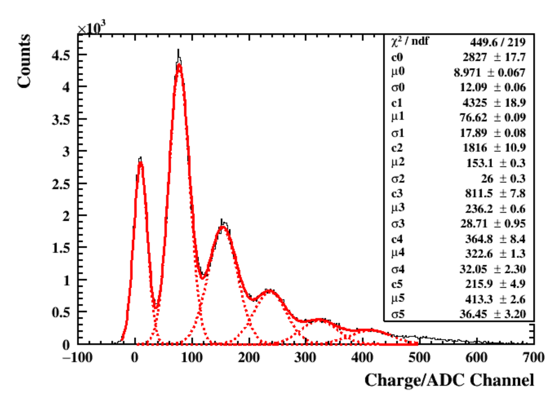
Signal Waveform



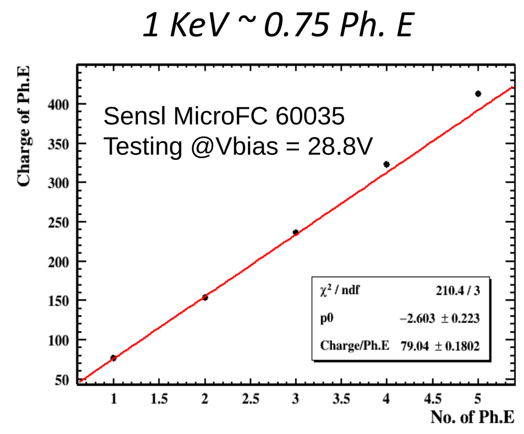
1 KeV ~ 0.75 Ph. E



Signal Rise Time

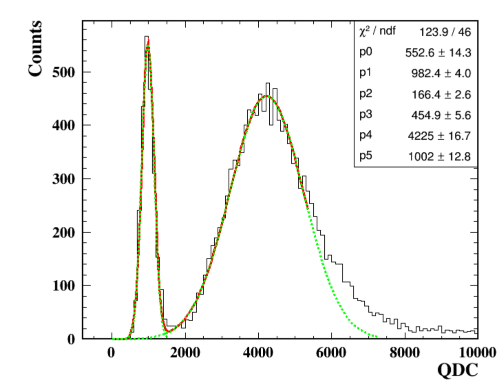


Multiphoton-electron Spectrum



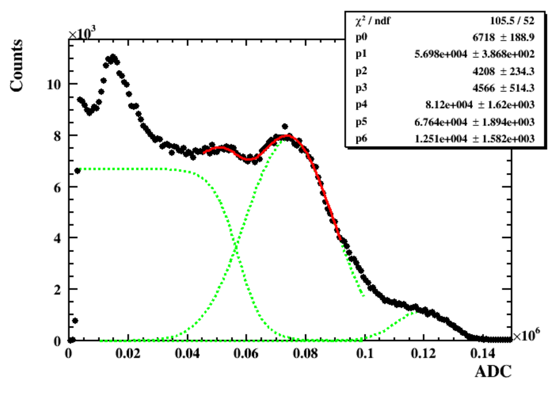
Signal Charge VS Number of Ph.E

Radioactive Sources Test



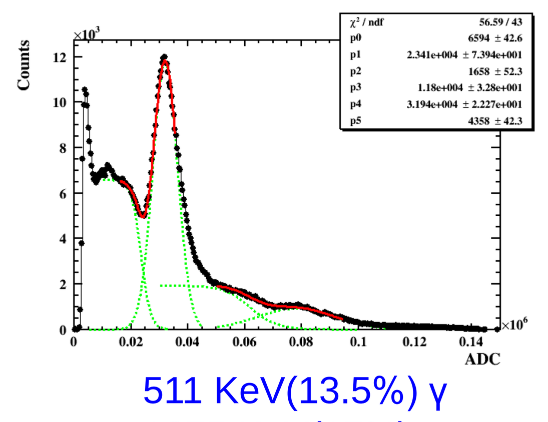
^{241}Am Energy Spectrum

59.6 KeV γ (23%)



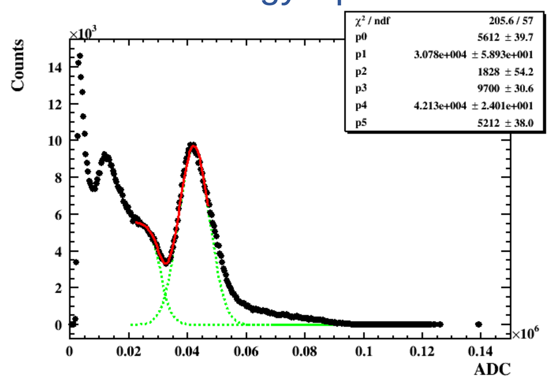
^{60}Co Energy Spectrum

1170 KeV + 1330 KeV γ



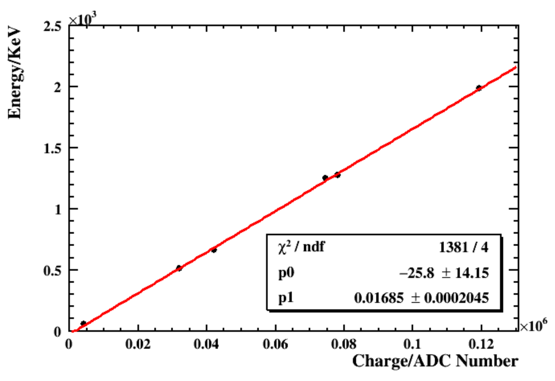
^{22}Na Energy Spectrum

511 KeV(13.5%) γ
1275 KeV(17%) γ



^{137}Cs Energy Spectrum

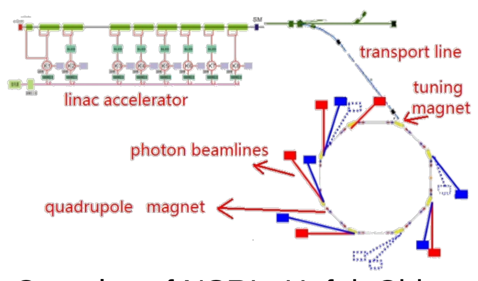
662 KeV γ (9.7%)



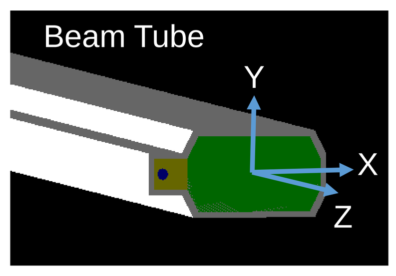
Energy Calibration

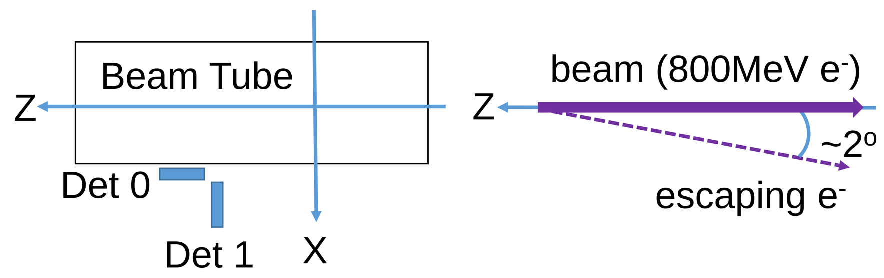
Sensitive to low energy gamma with good energy resolution and linearity

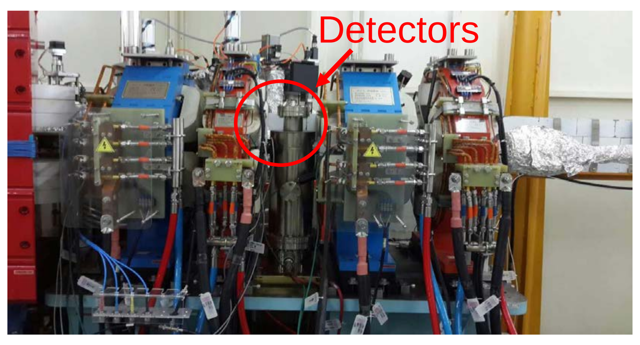
Beam Test at National Synchrotron Radiation Laboratory(NSRL)

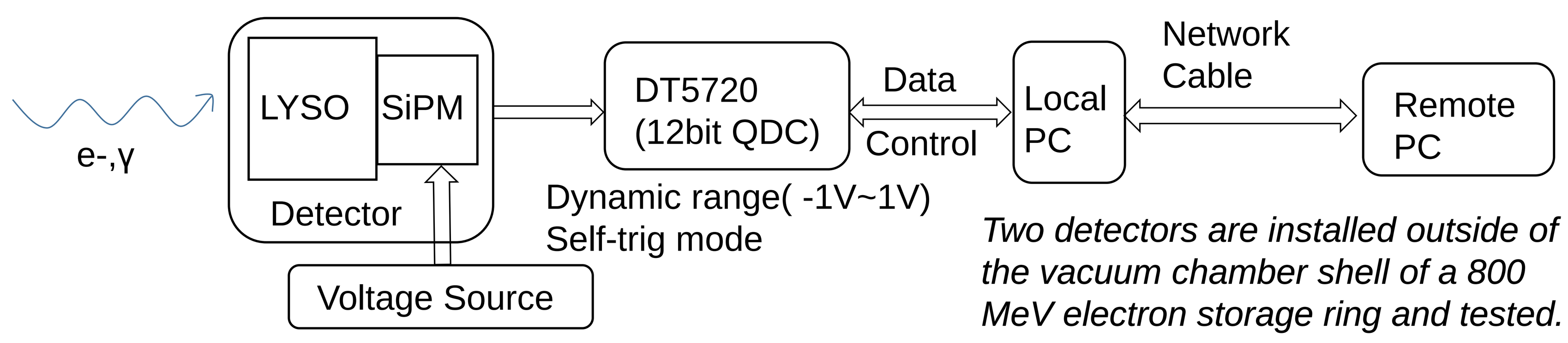


Complex of NSRL, Hefei, China





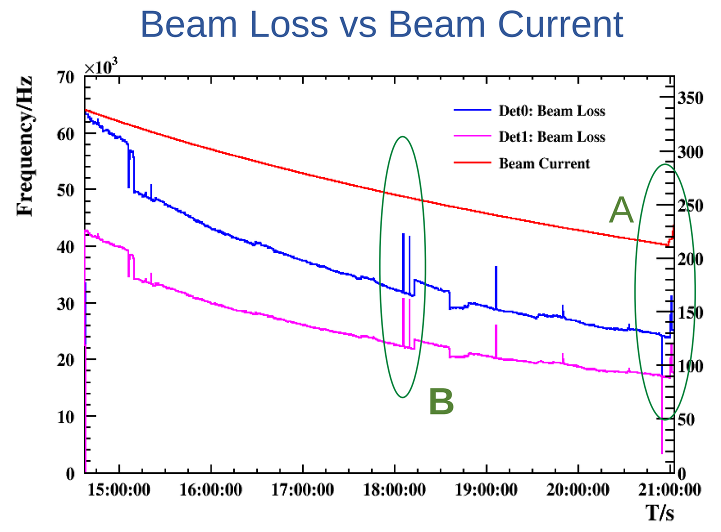


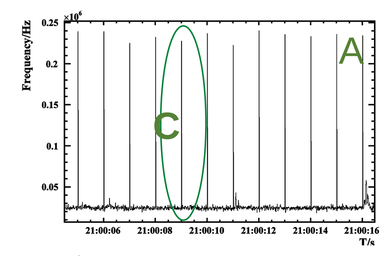


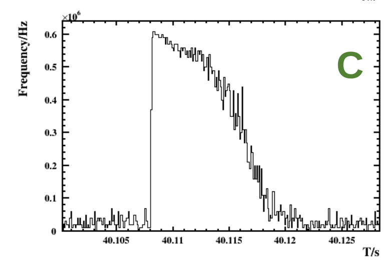
Two detectors are installed outside of the vacuum chamber shell of a 800 MeV electron storage ring and tested.

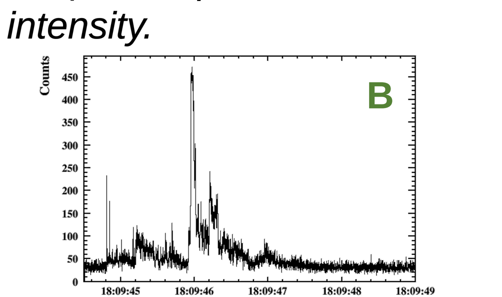
Beam Test and Simulation Results

Beam Loss vs Beam Current



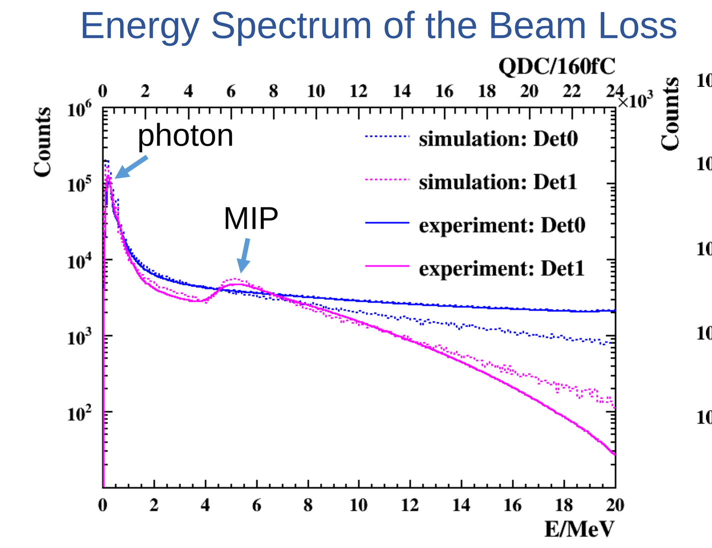




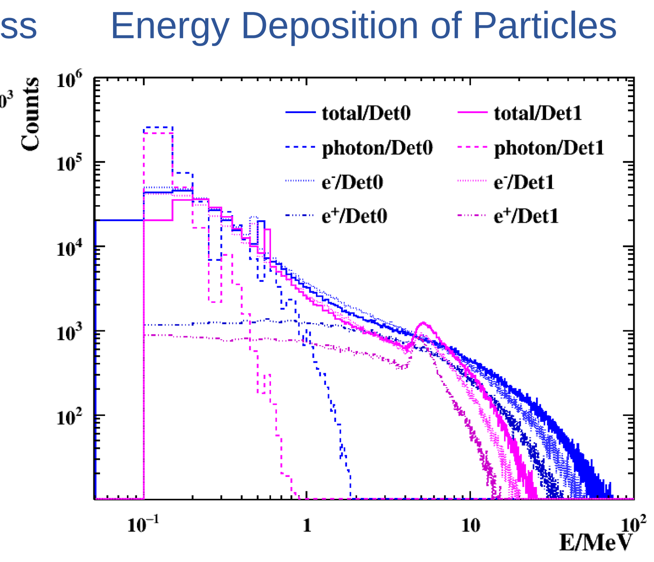


- ✓ *1Hz pulse-like beam loss could be detected during the injection of the beam.*
- ✓ *Could response to the loss <50μs, upon the loss intensity.*

Energy Spectrum of the Beam Loss



Energy Deposition of Particles



- ✓ *Multi-hit in some event.*
- ✓ *The energy of photon, which hit the detector, mainly <2MeV.*
- ✓ *For energy higher than 2 MeV, the spectrum is mainly contributed by electron and positron.*

Summary and Outlook

- *The design of a novel BLM detector is reported. The detector features fast response, radiation resistant, compact structure, as well as insensitive to magnetic field;*
- *The detector has a large dynamic range, keeping good sensitivity and linearly to photon and charged particle at an energy range from tens of keV to several MeV;*
- *The detector could response to the beam loss quickly. Sensitive to the beam loss caused by the changing of the beam condition, it could provide more detail information than beam current for furthermore diagnosis of the beam;*
- *The detectors still have a good performance after exposing to high background of several MeV to hundreds of MeV electrons for two months;*
- *Plan to test it at high intensity proton accelerator of Accelerator Driven Sub-critical System of China (C-ADS) and China Spallation Neutron Source (CNSR) this year.*