Muons, Inc.

A Gas-Filled Calorimeter for High Intensity Beam Environments

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Introduction

- We present concepts and ideas, with some simulation results
- There are still issues and challenges to be dealt with
- We do not yet have prototypes or funding to develop them
- We are trying to convey the spirit of the TIPP conference - innovation

Outline

- Concept 1: Gas-filled Cherenkov Calorimeter
  - Characteristics
  - Light collection : issues and approaches
  - Photon detectors: Requirements and candidates
  - Example applications
- Concept 2: SiPM detector with logarithmic response

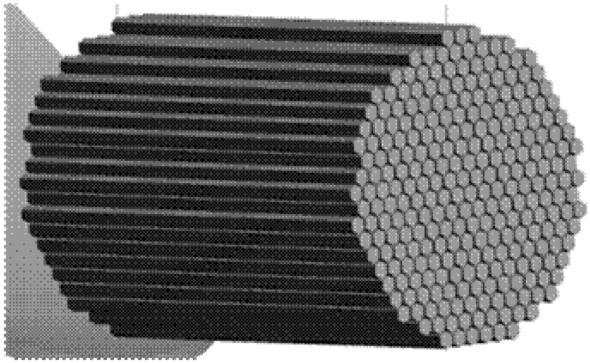
Concept 1: Gas-Filled Cherenkov Calorimeter

(a) Array of high-Z hexagonal rods

(b) Detail: light rays indicated in the gaps.

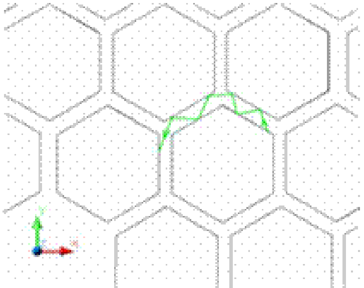
(c) Side view: 4 mm Pb rods and 2 mm gaps.

Red indicates electrons; green indicates **photons** generated by Cherenkov radiation.



(a)

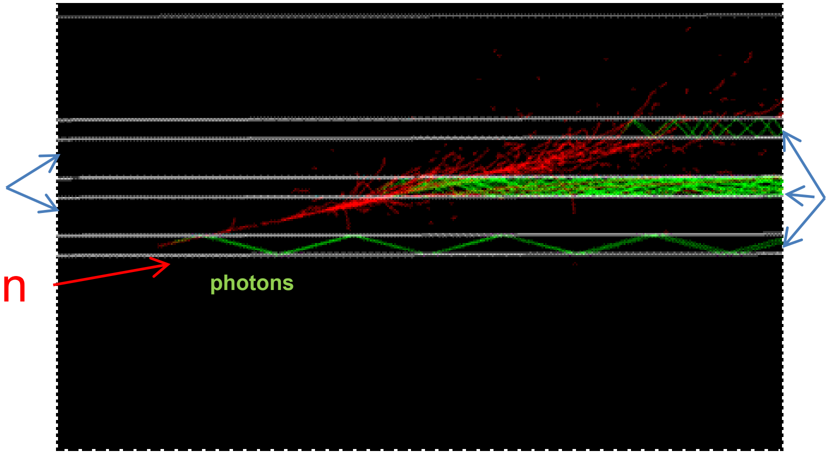
Group of rods
End view detail



(b)

rods

10 GeV incident electron



photons
In gaps

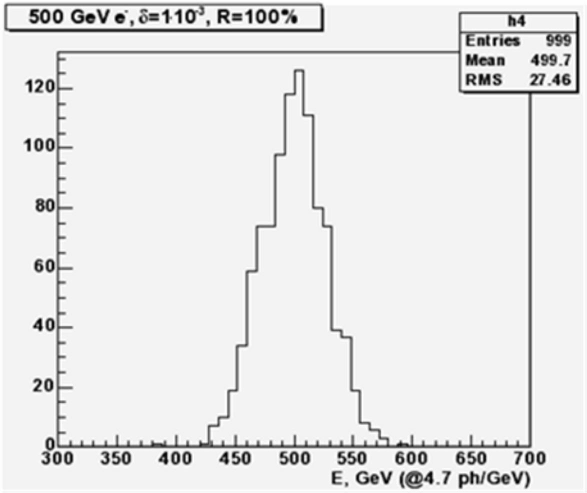
(c)

Design Features

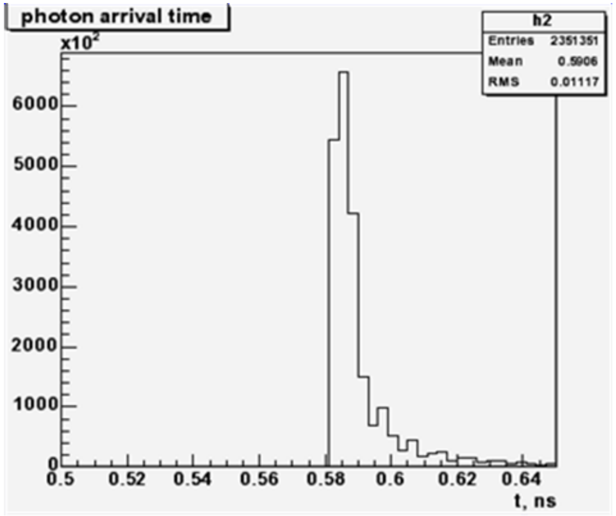
1. **Inherently fast:** Cherenkov light is produced instantaneously as the particles pass through the gas and the calorimeter is emptied of light within a nanosecond or two after the particles exit.
2. **Insensitive to radioactive decay products:** Threshold for Cherenkov radiation is ~10 MeV in gas. Provides stability for long term operation even if material becomes activated.
3. **Radiation-Tolerant:** Basic unit is metal and gas (except possibly for photon detectors) and not altered by large radiation exposure

Performance Simulation

500 GeV Electrons
30 X_0 W Calorimeter
1000 Events



(a)



(b)

Energy resolution: 5.4%

Photon arrival time at back of radiator:
RMS = 11 ps, FWHM(peak) = 11 ps

Challenge: Light Transport

- Efficiency of transport of the light is of great importance for the operation of gas-filled calorimeters.
- High reflectance surfaces or coatings are needed on the rods or tubes that carry the light to the photon detectors.
- With as many as 12 reflections along the conduits, the light signals can be severely attenuated if the reflectance is not excellent.
- Possible means to produce high reflectance surface:
  - Polishing techniques used for RF cavities
  - Atomic layer deposition
  - Chemical vapor deposition
- These need further investigation

Light collection

- The type of light collection system depends on many factors
  - Particle intensities expected at the downstream end of the array of rods or tubes that make up the calorimeter
  - Element sizes required for optimal segmentation of the output signals. These depend on:
    - shower sizes
    - particle multiplicities
    - the application and the radiation levels
- Examples of extreme cases of segmentation:
  - There is a detector at the end of each light guide element
  - All of the light from a calorimeter module is directed to a single detector, e.g. by means of a single mirror at the downstream end of the module.

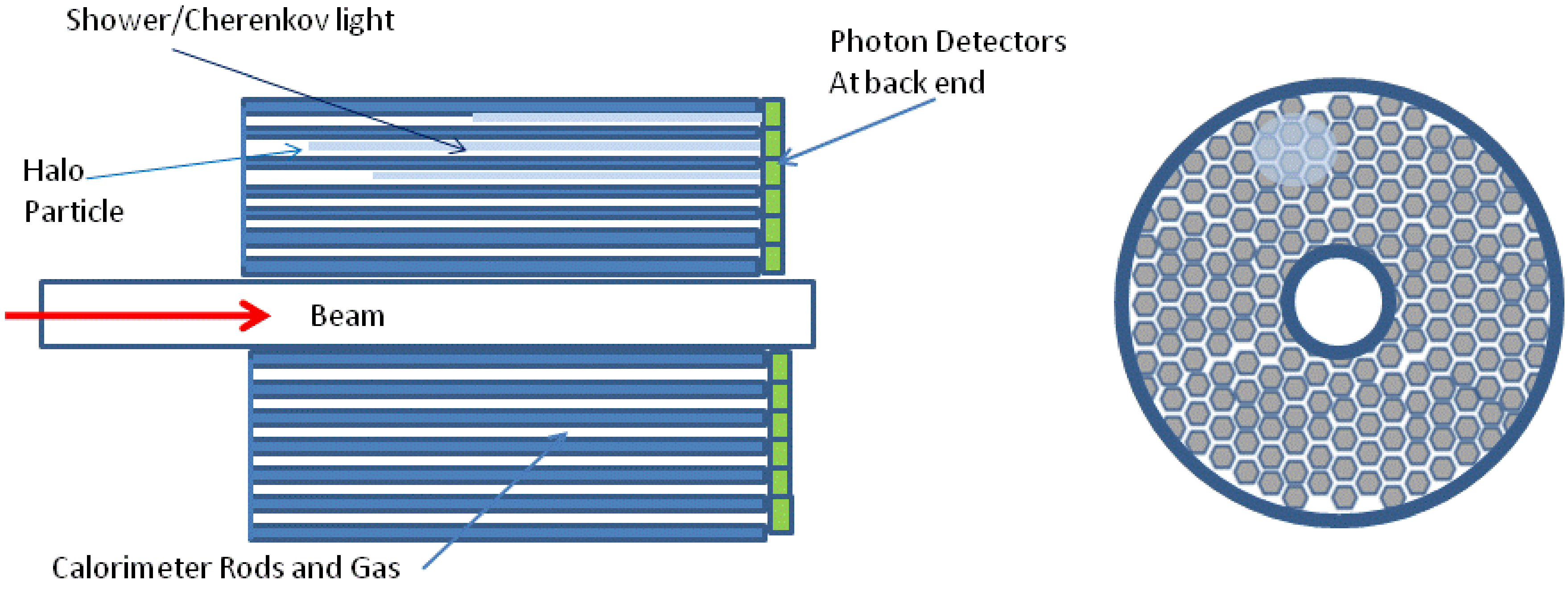
Photon Detectors

- Requirements
  - Fast (<~ 1 ns)
  - Broad dynamic range
  - Radiation-tolerant
- Candidates
  - SiPMs
  - Diamond detectors
  - MCPs
  - GEMs
- Also: Associated electronics must function in environment or be relocated

Hadron/Muon Detection

- Fill with scintillating gas to detect non-EM particles
  - Hadrons will interact and shower
  - Muons will produce small signal
  - Filters to separate Cherenkov light from scintillation light
- Scintillation light produced slower than Cherenkov light (~ns)
- Dual readout possible
- Further investigation needed

Example: Beam Halo Monitor



Shower/Cherenkov light

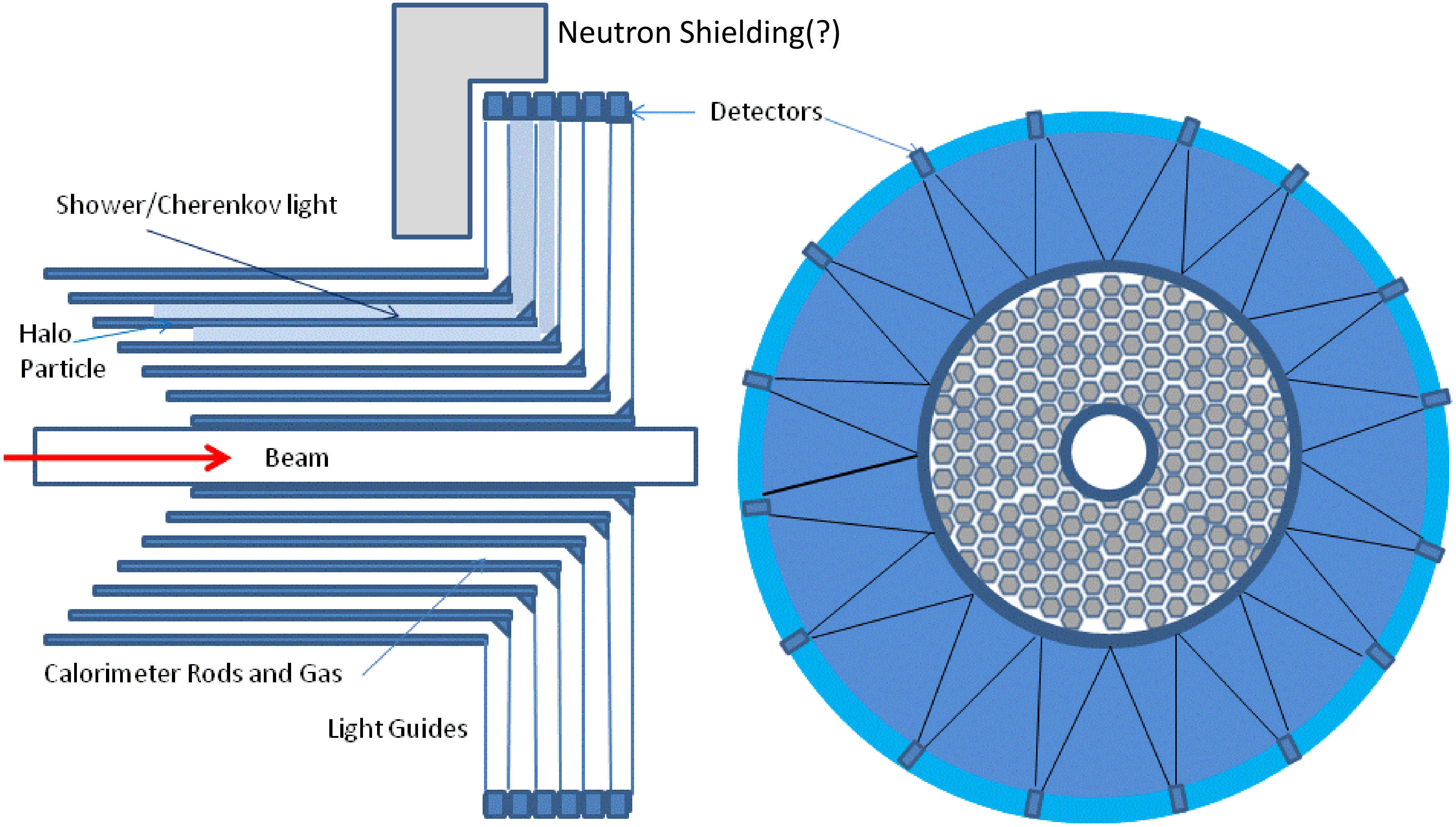
Photon Detectors
At back end

Halo
Particle

Beam

Calorimeter Rods and Gas

Beam Halo Monitor – Detectors Offset to Reduce Radiation Exposure

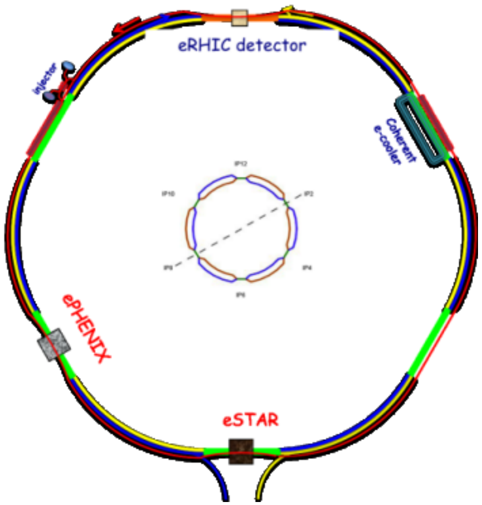


Segmentation
In depth as
needed

Angular
Segmentation
as needed

Not to scale

Potential Applications for Gas Ĉ Halo Monitors and/or Calorimeters



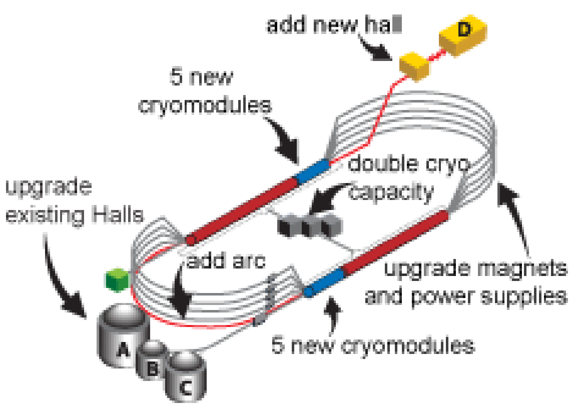
e-RHIC

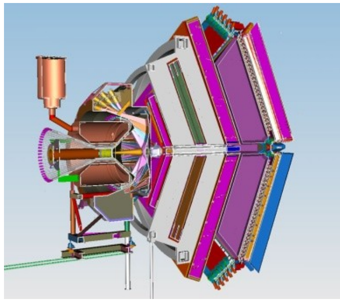
5-30 GeV electrons
50-325 GeV polarized protons or up to 130 GeV/u gold ions

$\mathcal{L} > 10^{34}$ cm^{-2}s^{-1} for e-p collisions , $> 10^{32}$ cm^{-2}s^{-1} for e-Au

CEBAF Upgrade:

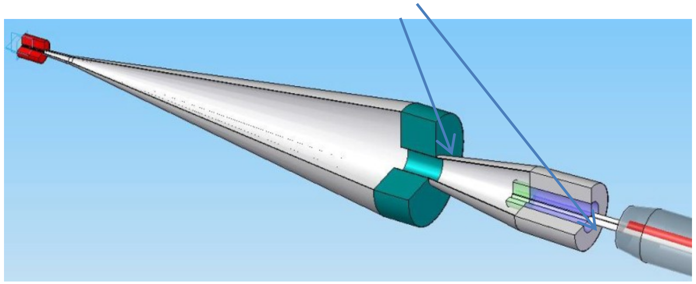
from 6 GeV → 11 GeV electrons
40x increased luminosity



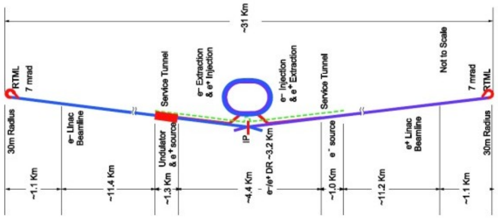


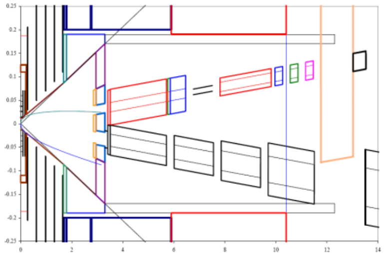
CLAS12 - CLAS upgraded to higher (10^{35}) luminosity and coverage

Muon Collider Forward Region[#]



ILC MDI and Forward Region*





[#] M. Demarteau, Muon Collider DOE Briefing, 2009

*Drake, et al, ILC07

Concept 2: SiPM-based logarithmic-scale photo-converter

High intensity machines beam backgrounds may vary over many orders of magnitude. A photo-detector with logarithmic response can operate over a wide range of intensities

- **SiPM detector properties**
  - SiPMs consist of ~1000 Geiger cells over an area of a few mm-square. They have exceptional single photon counting capabilities, good signal-to-noise, high speed, and robustness even for complete saturation of all Geiger cells.
  - They can operate in high magnetic fields and can operate in full daylight at full voltage.
- **Logarithmic-scale photo-converter**
  - SiPM silicon structures can be made partially transparent to light in the visible.
  - For 10% transparency, 90% of the incident light will trigger Geiger cells, and 10% of the light will emerge from the back of the silicon substrate.
  - Mounting a second SiPM below the first one will intercept the transmitted 10%, and pass 1% of the light, and so on through a stacked array of SiPMs.

Example: Mean number of Geiger cells struck, within SiPM time window, for 10-layer stack of SIPMs, with 1000 Geiger cells per layer, and transparency of 10%. "Sat" means that all of the 1000 Geiger cells in the SiPM are hit, and the SiPM is fully saturated.

	Low Intensity	Medium	High	Very High
SiPM Layer	**10 photons incident**	**10^4 photons incident**	**3.10^5 photons incident**	**10^9 photons incident**
1	~10	1000 (sat)	1000 (sat)	1000 (sat)
2	~ 1	~ 100	1000 (sat)	1000 (sat)
3	0	~ 10	1000 (sat)	1000 (sat)
4	0	~ 1	~ 270	1000 (sat)
5	0	0	~ 30	1000 (sat)
6	0	0	~ 3	1000 (sat)
7	0	0	0	~ 900
8	0	0	0	~ 100
9	0	0	0	~ 10
10	0	0	0	~ 1

What’s Next - Future Plans

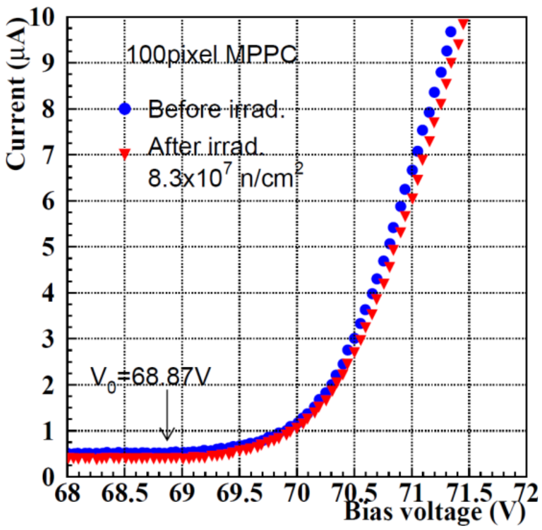
- Perform more simulations: Hadron showers, lower energy electomagnetic showers
- Investigate making high reflectance surfaces
- Investigate scintillating gases and dual readout designs.
- Design, build and test prototype modules.
- Further investigate suitable photon detectors
- Test logarithmic response detector concept
- Investigate applicability for collider detector calorimeters as well as beam halo monitors

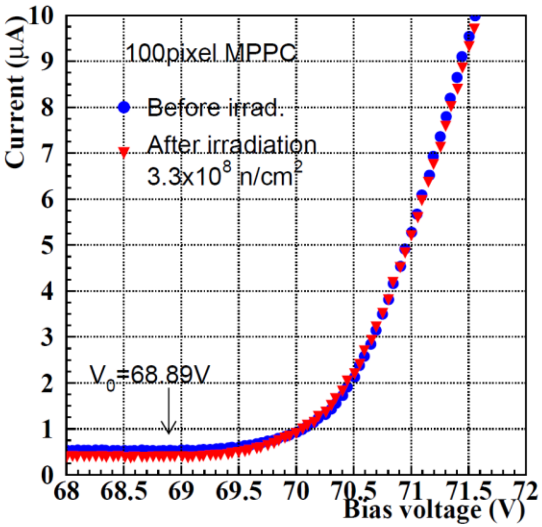
Appendix

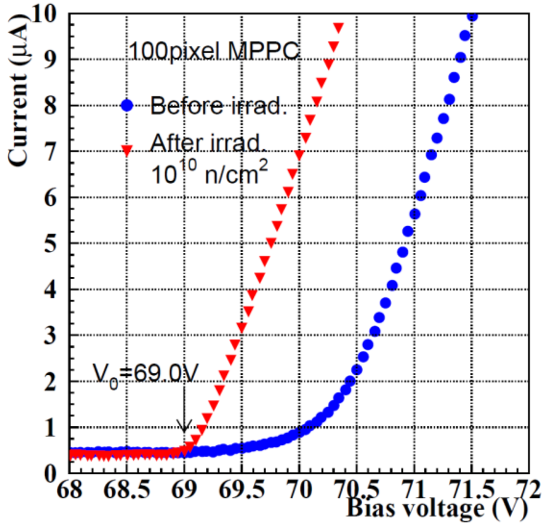
SIPM properties

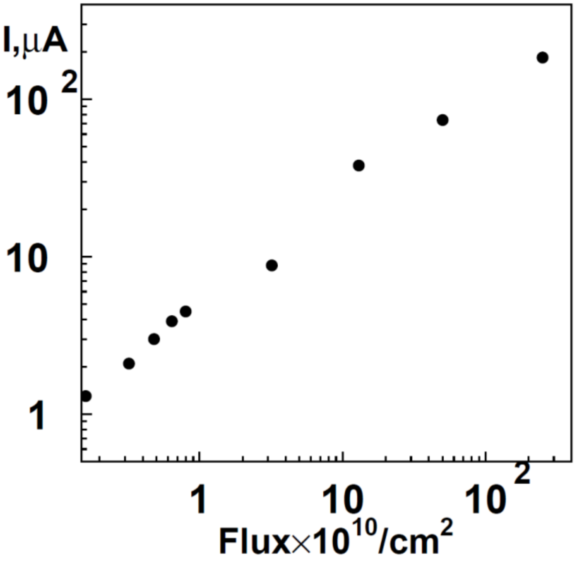
- Good performance in magnetic fields
- Low bias voltage (~50V)
- Small size
- Radiation tolerance issues
  - Increased dark current
  - Increased after-pulsing
  - Recovery takes long time
  - Neutrons worse than electrons

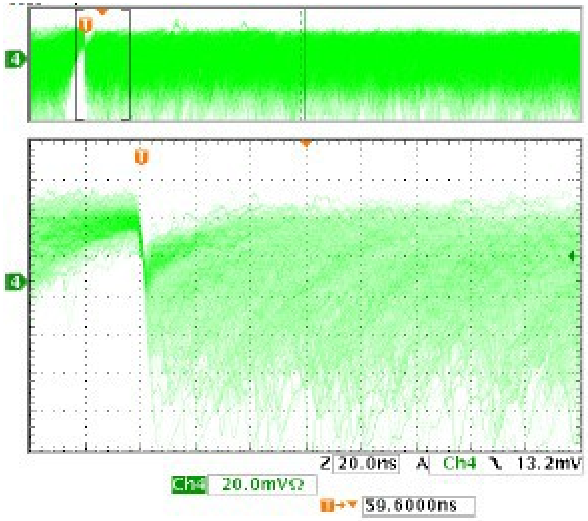
Radiation damage to SiPM: neutrons (0.1 -1 MeV) (Matsumura, 2009)

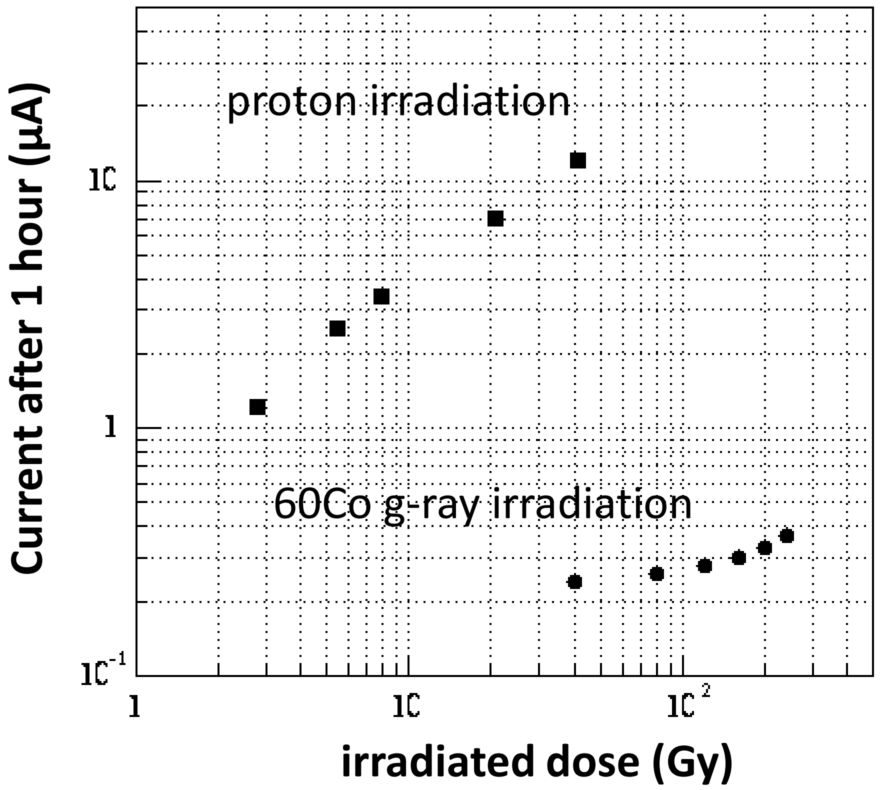


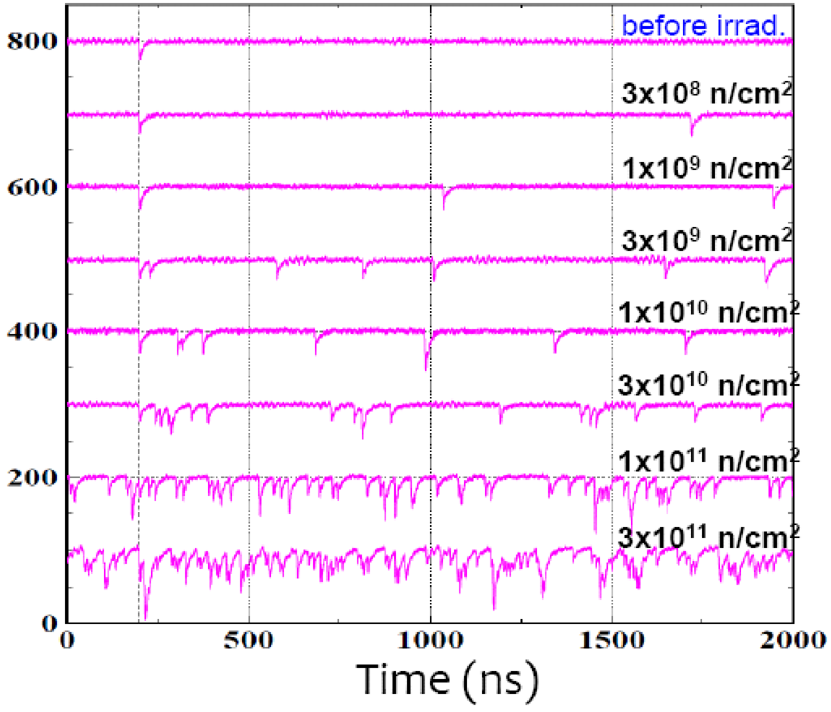












I.Nakamura, JPS meeting, Sep. 2008

Very hard to use present SiPMs as
single photon detectors
under p, n irradiation

Comparison of Photon Detectors*

- MCP-PMT radiation hardness:
  - No major deterioration up to 10 ^{14} neutrons/cm ^{2} for Hamamatsu R3809U-50 (Piotrzkowski, GasTof note, 2008)
- Anodic aluminum oxide MCP:
  - Intrinsically radiation-hard

*S. Korpor, S-KEKB mtg , Dec, 2008