

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

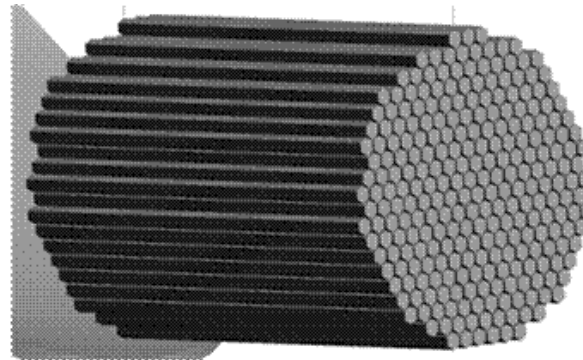
Outline

- 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

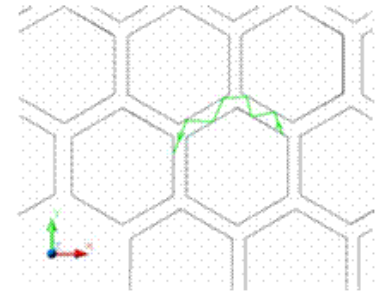
- (a) Array of high-Z hexagonal rods
- (b) Detail: light rays indicated in the gaps.
- (c) Side view: 4 mm Pb rods and 2 mm gaps.

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

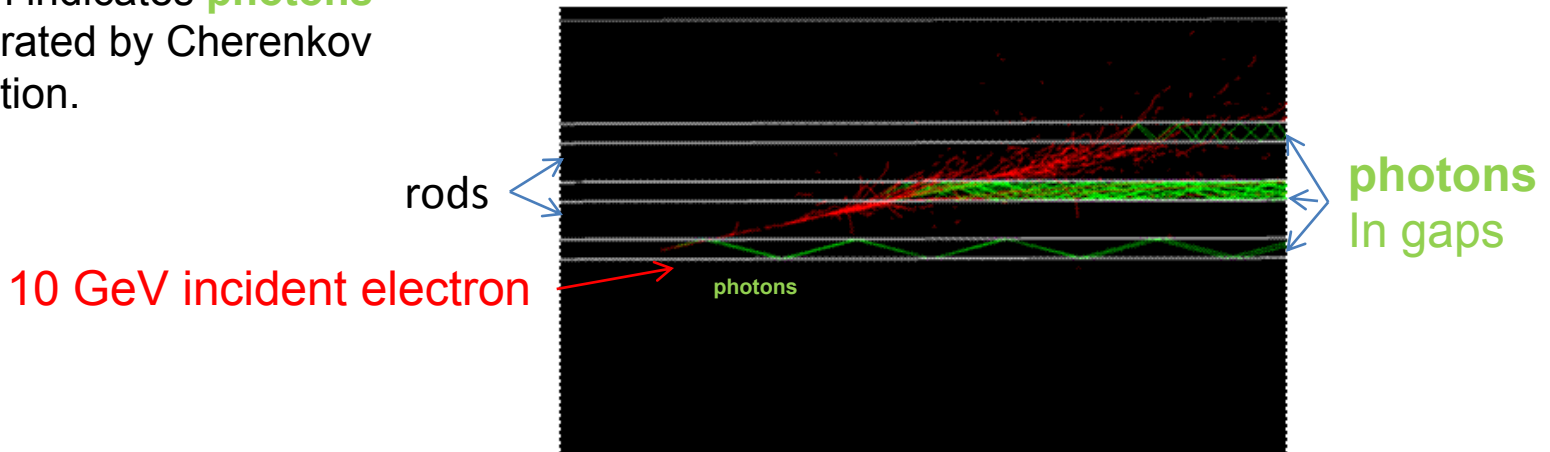


{a}

Group of rods
End view detail



{b}



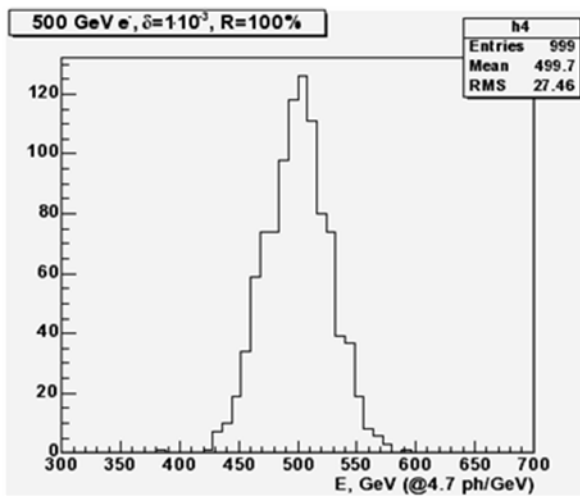
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Design Features

- 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

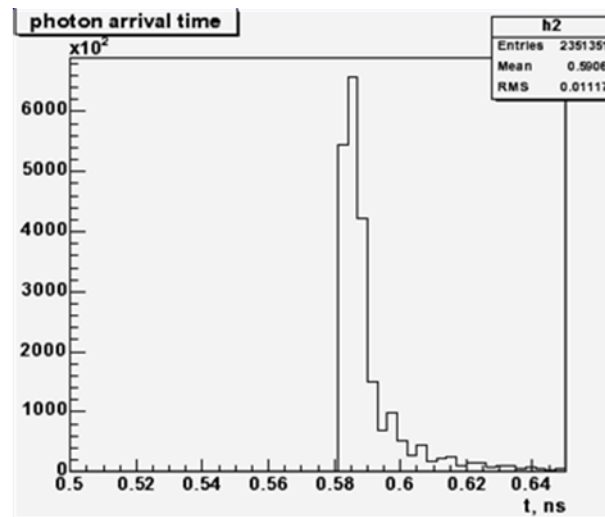
Performance Simulation

500 GeV Electrons
30 X_0 W Calorimeter
1000 Events



(a)

Energy resolution: 5.4%



(b)

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.

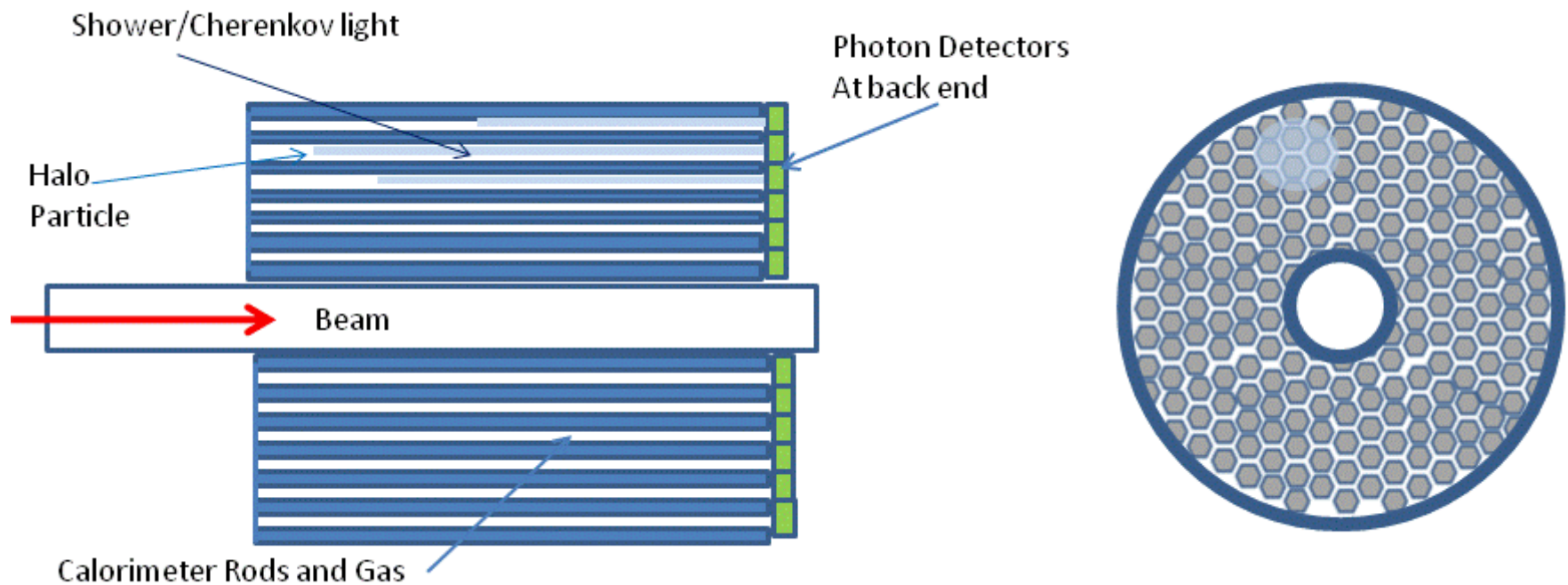
Photon Detectors

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

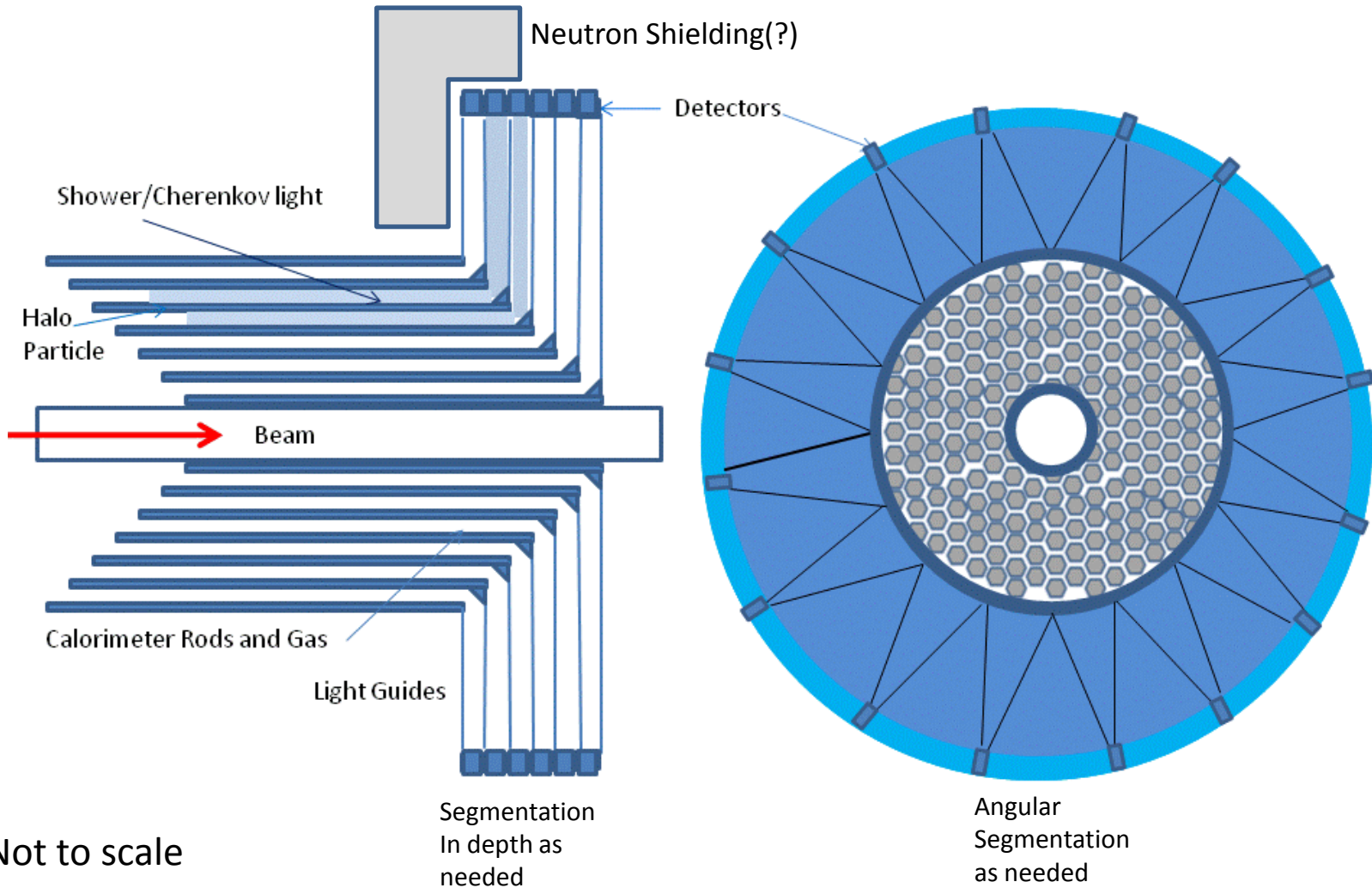
Hadron/Muon Detection

- 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 (\sim ns)
- Dual readout possible
- Further investigation needed

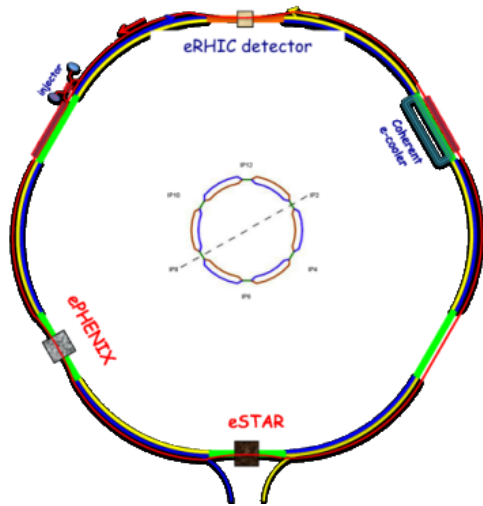
Example: Beam Halo Monitor



Beam Halo Monitor – Detectors Offset to Reduce Radiation Exposure



Potential Applications for Gas \hat{C} Halo Monitors and/or Calorimeters



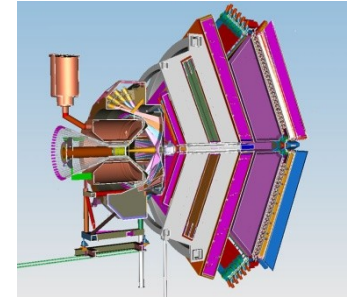
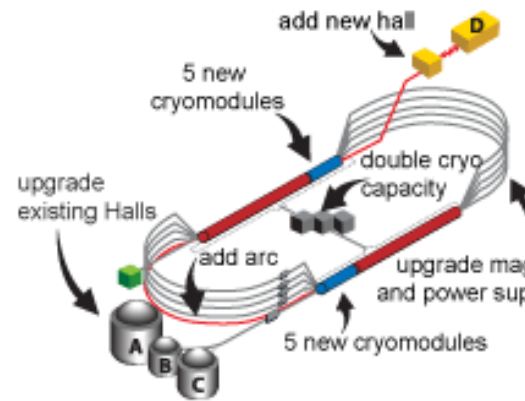
e-RHIC

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

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

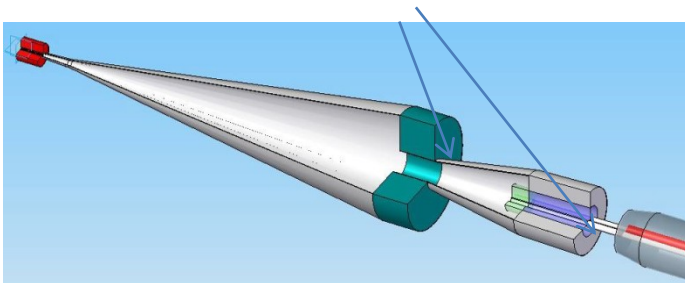
CEBAF Upgrade:

from 6 GeV \rightarrow 11 GeV electrons
 40x increased luminosity



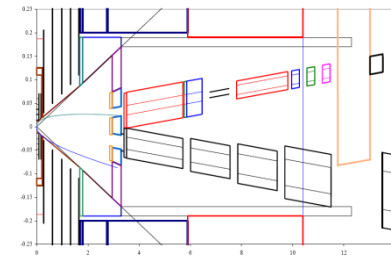
*CLAS12 - CLAS upgraded
 to higher (10^{35})
 luminosity and coverage*

Muon Collider Forward Region[#]



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

ILC MDI and Forward Region^{*}



^{*} 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	$3 \cdot 10^5$ 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

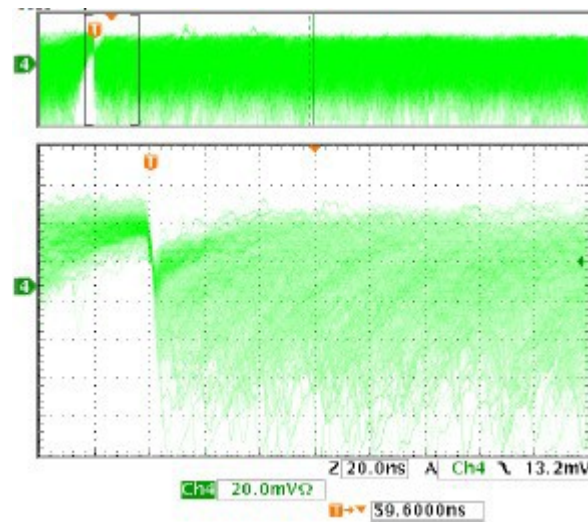
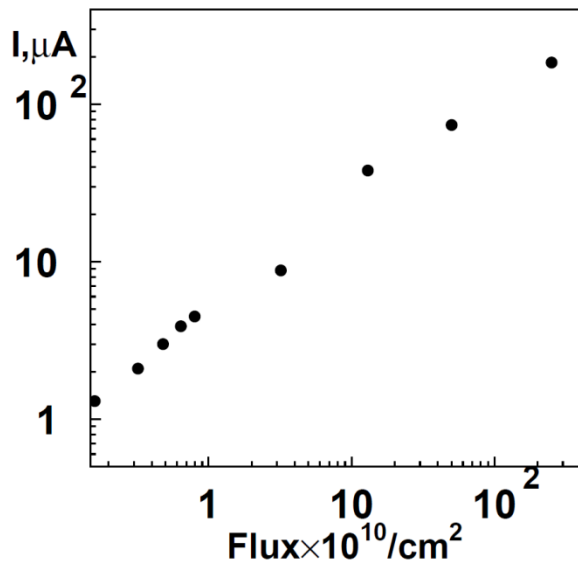
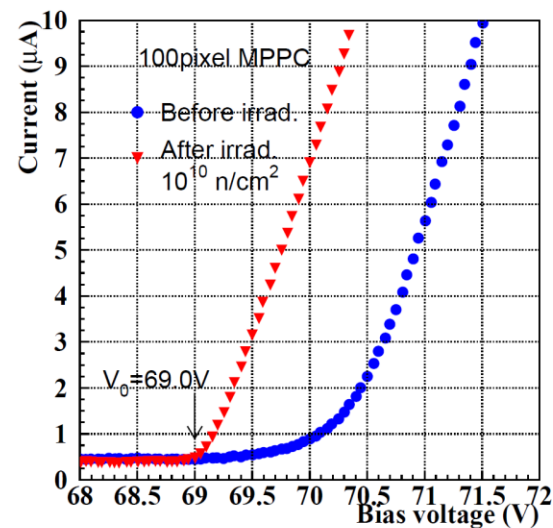
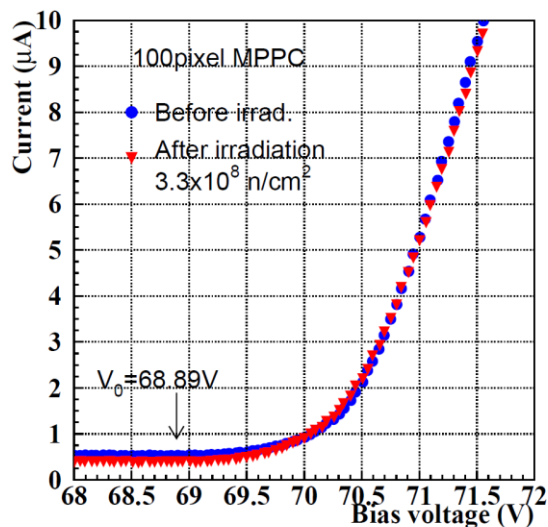
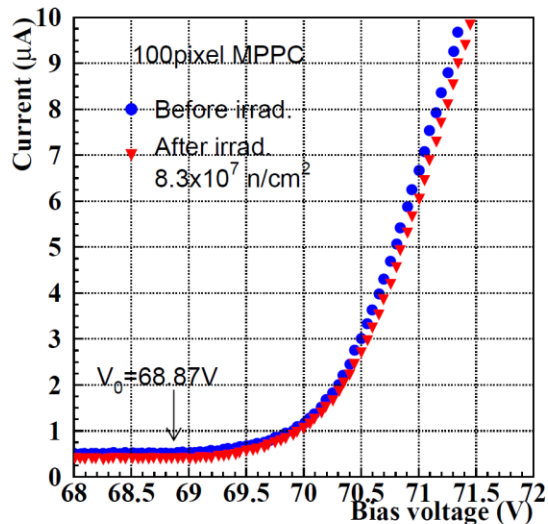
- Perform more simulations: Hadron showers, lower energy electromagnetic showers
- Investigate making high reflectance surfaces
- Investigate scintillating gases and dual readout designs.
- Design, build and test prototype modules.
- Further investigate suitable photon detectors
- Test logarithmic response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

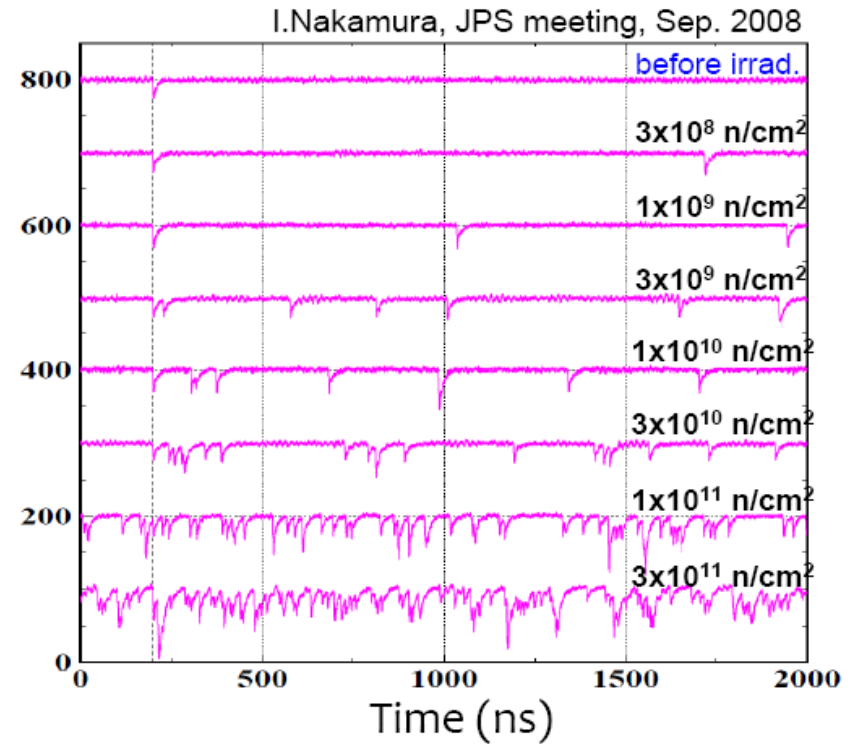
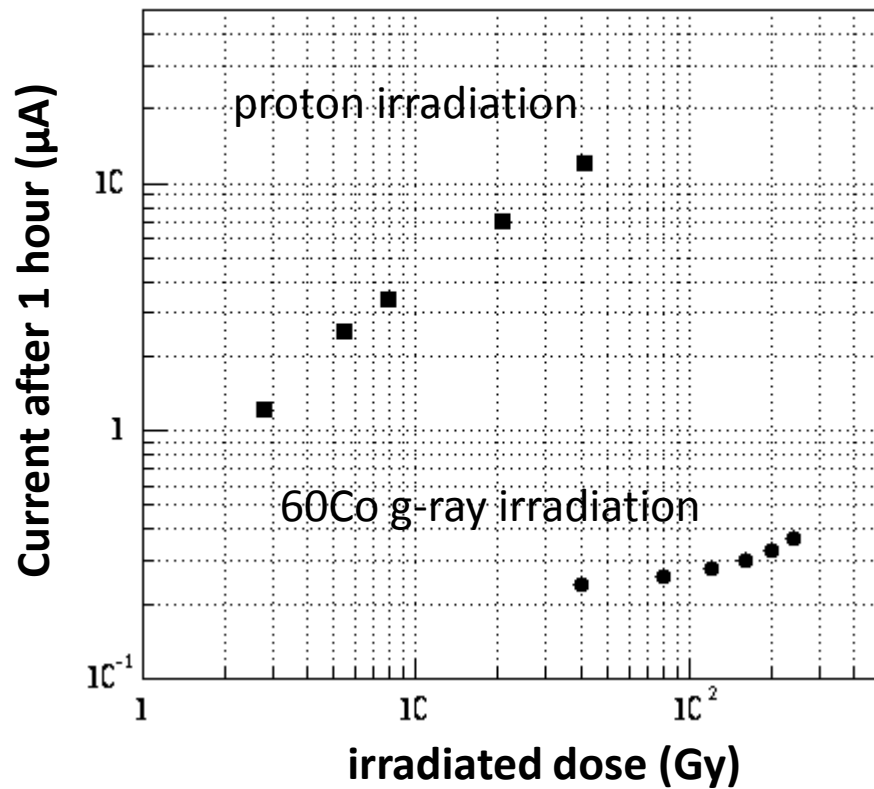
Appendix

SIPM properties

- Good performance in magnetic fields
- Low bias voltage ($\sim 50\text{V}$)
- 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)





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/cm² for Hamamatsu R3809U-50 (Piotrkowski, GasTof note, 2008)
- Anodic aluminum oxide MCP:
 - Intrinsically radiation-hard

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