Cerenkov Detectors: Radiation Tolerance & Helium Issue

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LUXE technical meeting
15th July 2020

The Helium issue

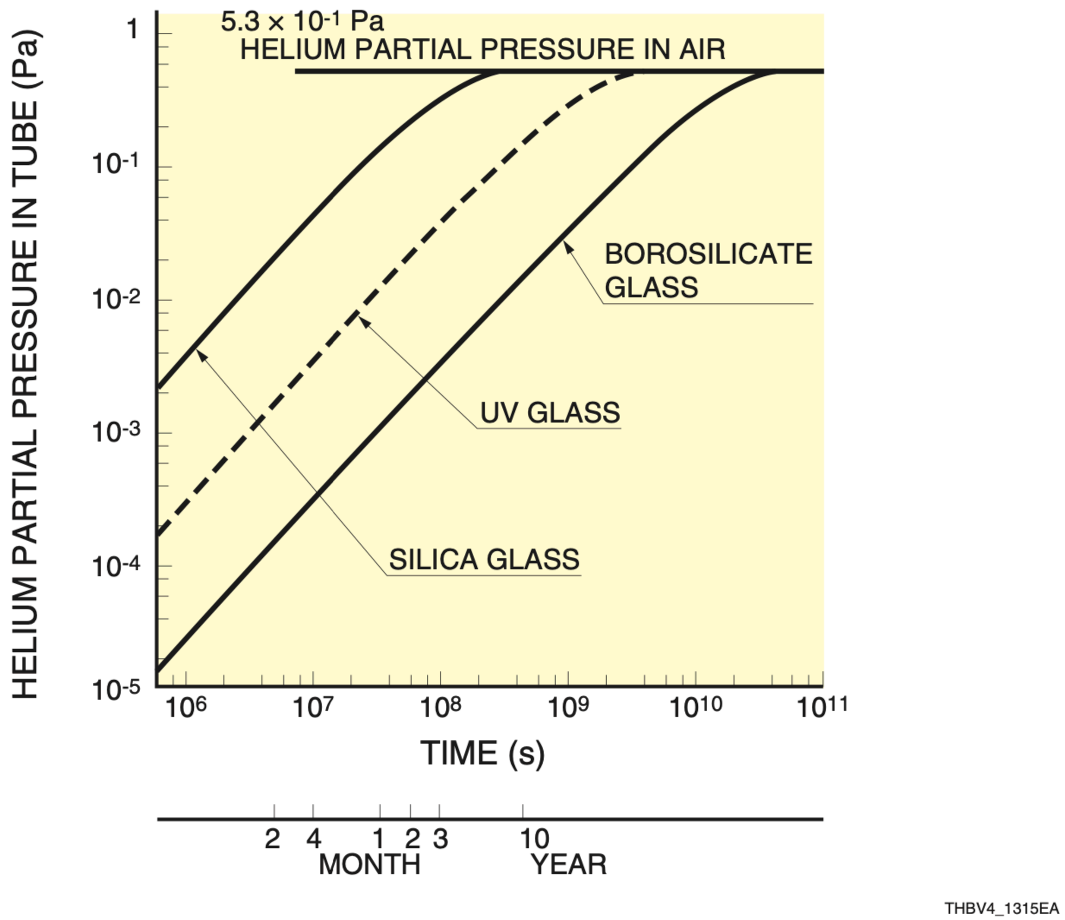


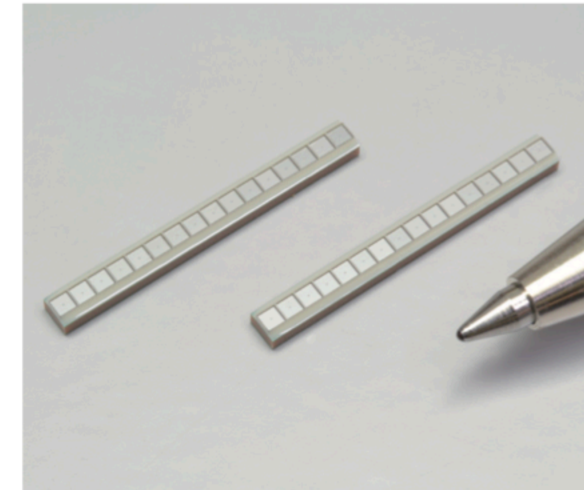
Figure 13-15: Bulb materials and variations in helium partial-pressure inside photomultiplier tubes

Medium	Refractive Index n
C_4F_{10}	1.0014
Air/Argon (15°, 1atm)	1.00028
Helium (0°, 1atm)	1.000036

- originally proposed to use Helium as a Cerenkov gas (very low refractive index)
- problem: Helium diffuses through Silica glass (and basically everything else)
- increases the gas pressure within the photodetector
- leads to afterpulses, eventually to breakdown of the tube
- Hamamatsu: gaseous PMTs should not be operated in Helium environments
- Helium is also problematic wrt gas tightness…

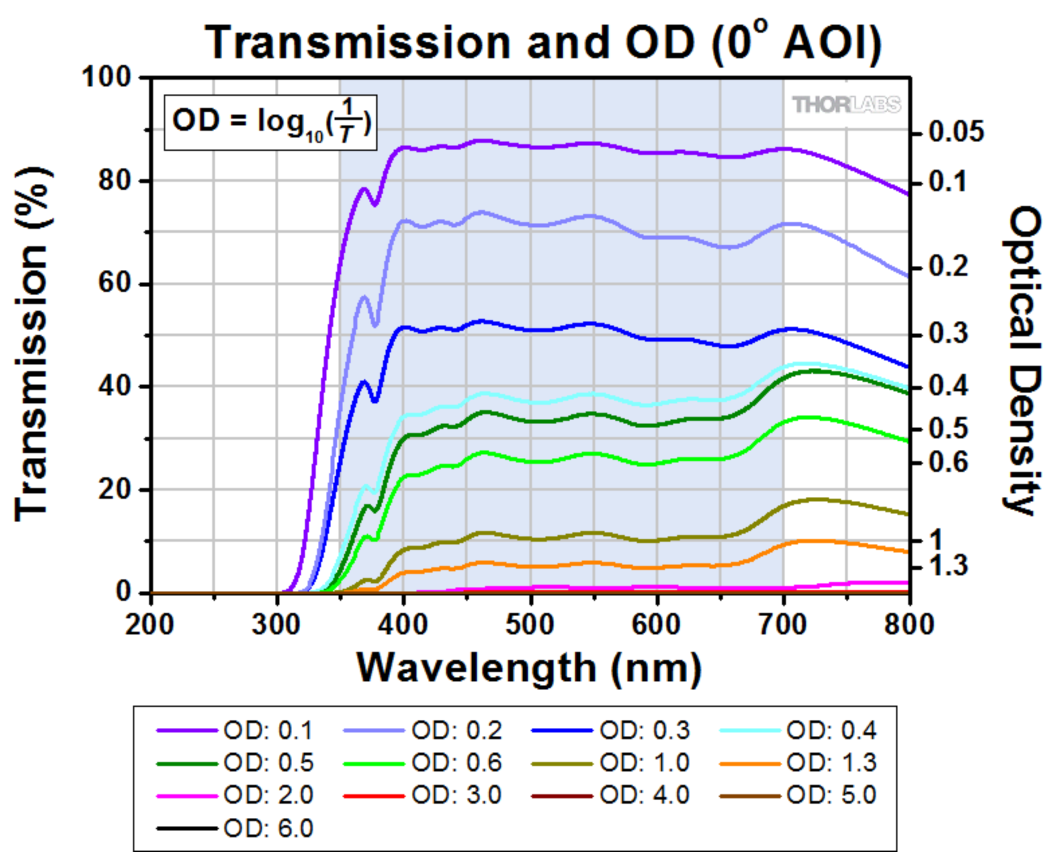
Cannot use Helium + normal PMT tube → Argon instead?

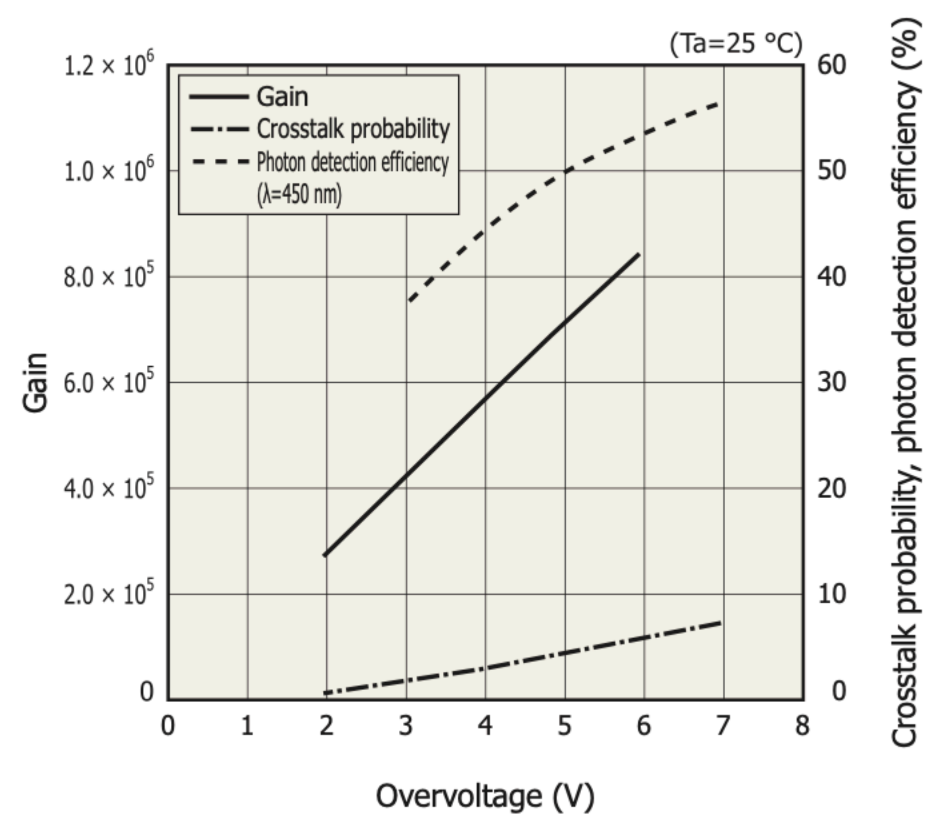
Si PMTs + Filters



1 × 16 ch

- Silicon PMT (e.g. Hamamatsu S13315 series)
- advantage: - easier to have fine channel segmentation (1x1mm)
  - cheaper (8x8 1x1mm anodes - 600$, no HV needed)
  - flexible anode configuration
  - immune to magnetic fields
  - no “burn-in” effect for high light intensities
- gain is 10^5-10^6, can not be reduced indefinitely (breakdown)
- absorbtive neutral-density filter to reduce light intensity (can get down to 0.01% transmission)



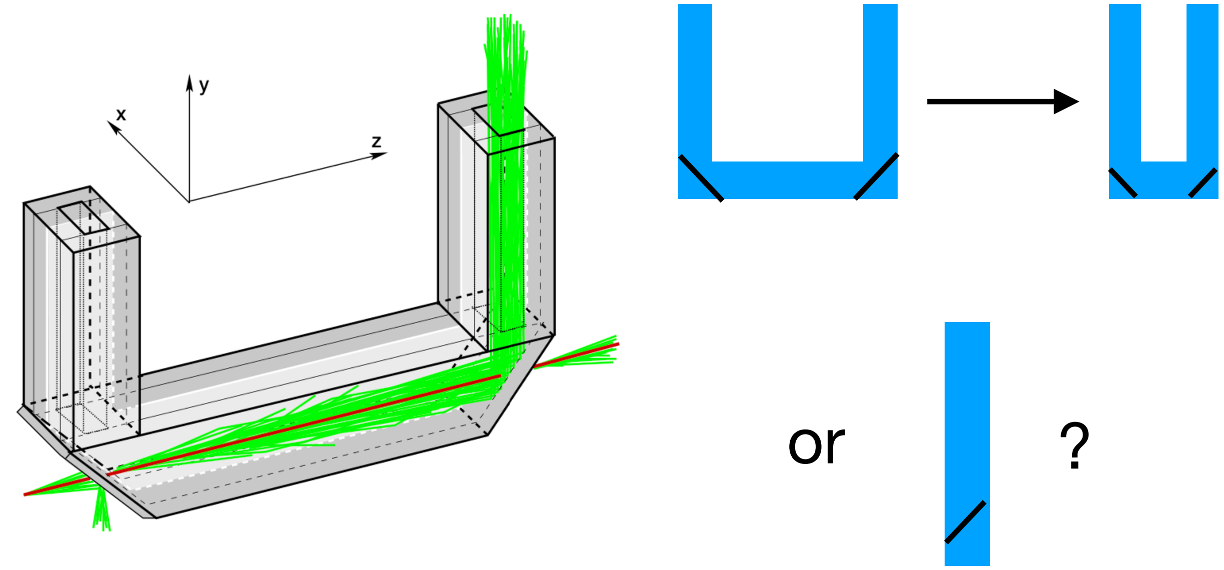


Rate mitigation before

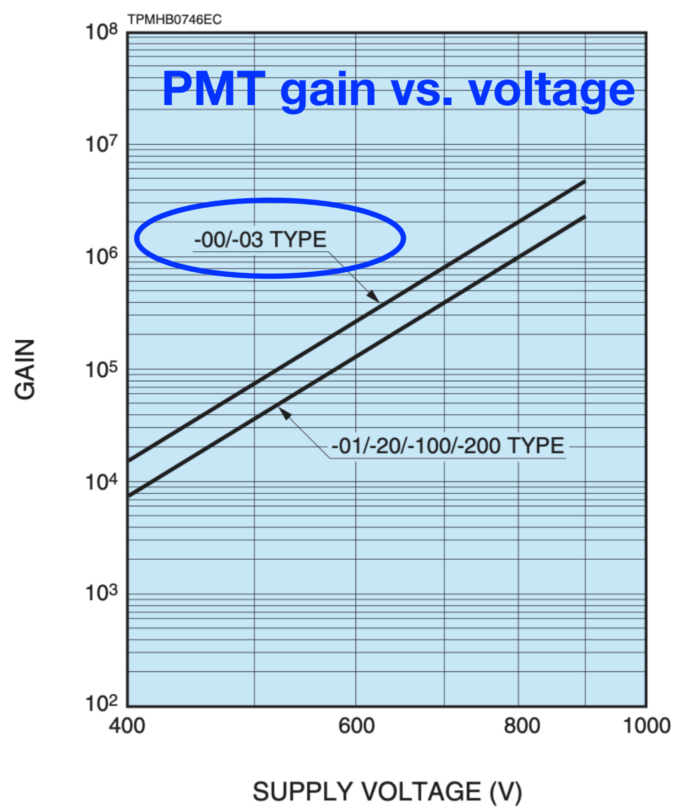
$$N_\gamma = 2\pi\alpha l_z\left(1 - \frac{1}{n^2}\right)\left(\frac{1}{\lambda_{\min}} - \frac{1}{\lambda_{\max}}\right)$$

Medium	Refractive Index n	N_γ per primary 300-650nm	N_γ per primary 185-650nm
C_4F_{10}	1.0014	230	495
Air/Argon (15°, 1atm)	1.00028	46	100
Helium (0°, 1atm)	1.000036	6	13

Gas: reduction by factor ~40!



Geometry: reduction by factor ~10!



Gain: reducing PMT operating voltage
→ reduction factor ~100!

→ Can reach necessary reduction of PMT anode charge by ~4 orders of Magnitude!

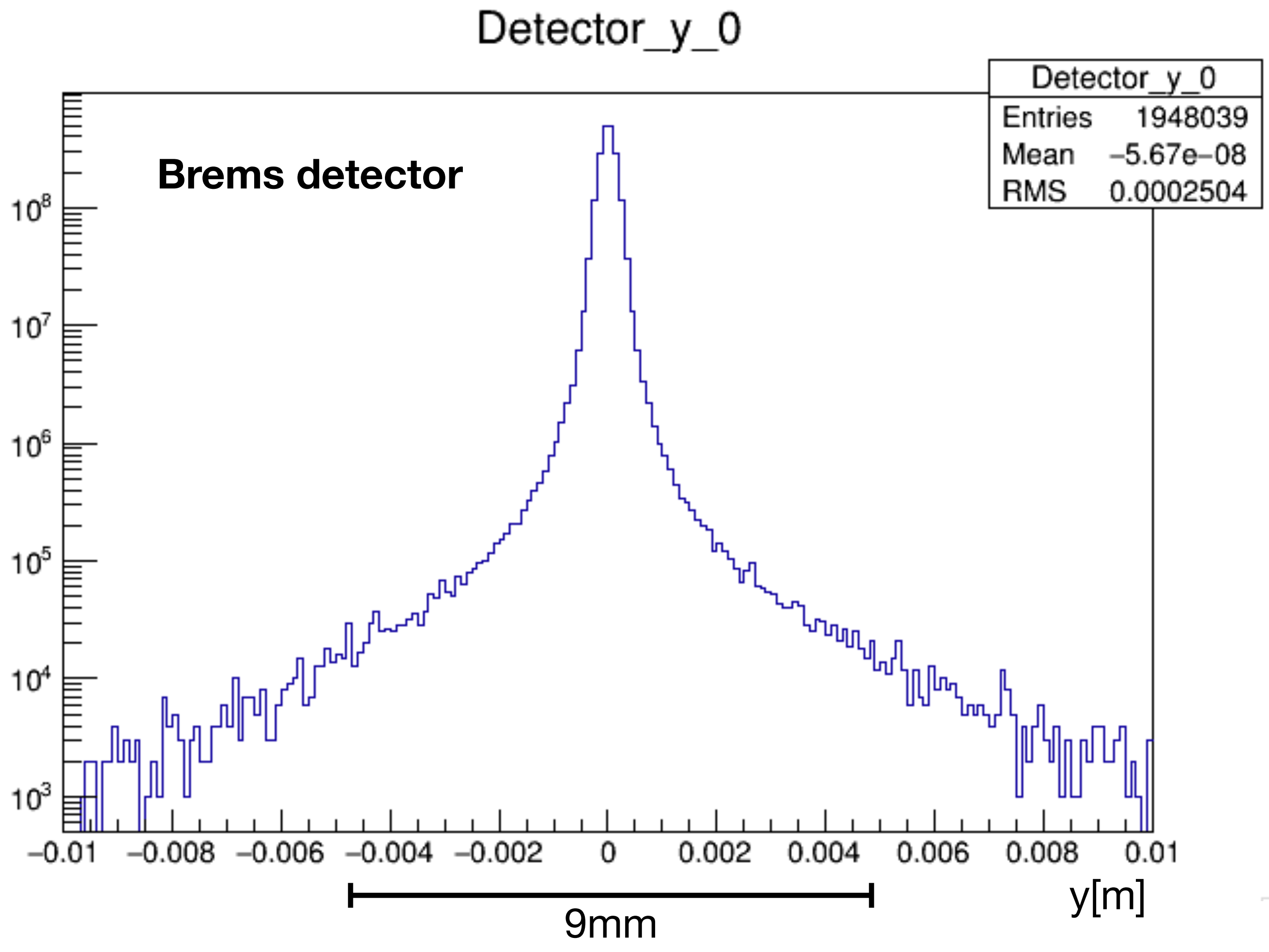
Comparison

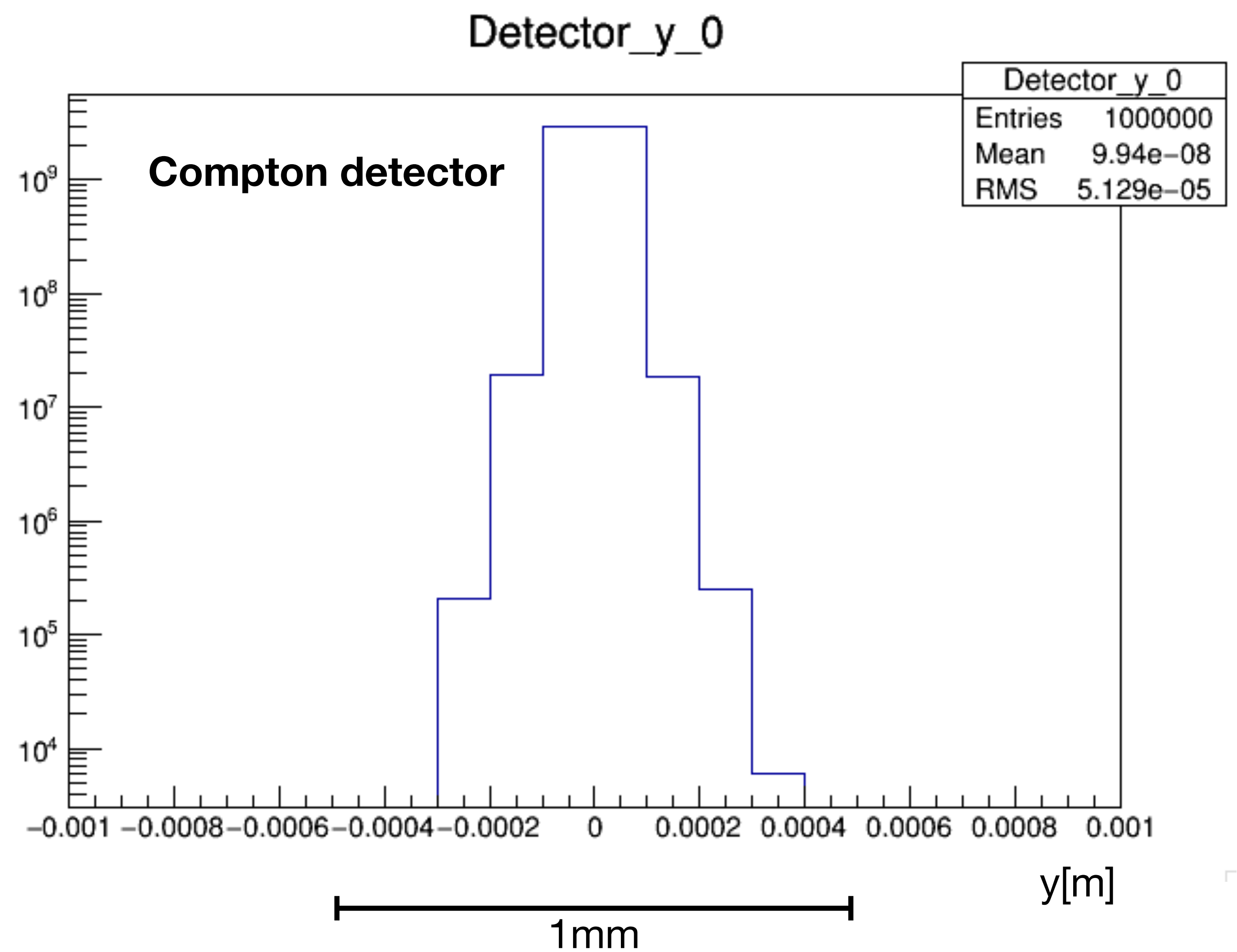
Action	Reduction Factor (He+Gas PMT)	Reduction Factor (Ar+SiPMT+Filter)
C_4F_{10} → Helium	40	x
C_4F_{10} → Argon	x	5
Lower PMT voltage	25	x
Shorter channel	10	10
SiPMT + Neutral Density Filter (0.1% Transmission)	x	1000
TOTAL	10^4	$5x10^4$

→ Can reach necessary reduction of anode charge!

Impact on Channel Dimensioning

- before,used 18mm y-channel width by default (size of PMT anode), but with SiPMT could go lower





Brems: - use 9x9mm channels
- need additional collimation/shielding!
- scattering on box?

Compton: - use 1x1mm channels

Radiation tolerance

- radiation damage in gases: radiation changes chemical properties of the gas (i.e. dissolution of covalent molecule bonds, polymerization)
- noble gases are least susceptible to radiation damage (high ionization potential, especially Helium)
- most relevant process for noble gas is nuclear transmutation
- most studies done for wire chambers, where main damage occurs in avalanches
  → should really be safe!

“Typical Cherenkov media like gases or quartz are sufficiently radiation hard to withstand the flux of 10^7 electrons passing through the detector per second.”

https://arxiv.org/pdf/1011.6314.pdf

3 **Design and Construction of a Cherenkov Detector for**
4 **Compton Polarimetry at the ILC**

5 Christoph Bartels[1,2], Joachim Ebert[2], Anthony Hartin[1],
6 Christian Helebrant[1], Daniela Käfer[1], and Jenny List[1]

“Only a limited choice of aging resistant gases can be successfully used in the high intensity experiments: noble gases, CF_4, CO_2, O_2, H_2O.”

https://arxiv.org/pdf/physics/0403055.pdf

RADIATION DAMAGE AND LONG-TERM AGING IN GAS DETECTORS[1]

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Institute of Theoretical and Experimental Physics (ITEP), B. Cheremushkinskaya, 25, Moscow, 117259, Russia

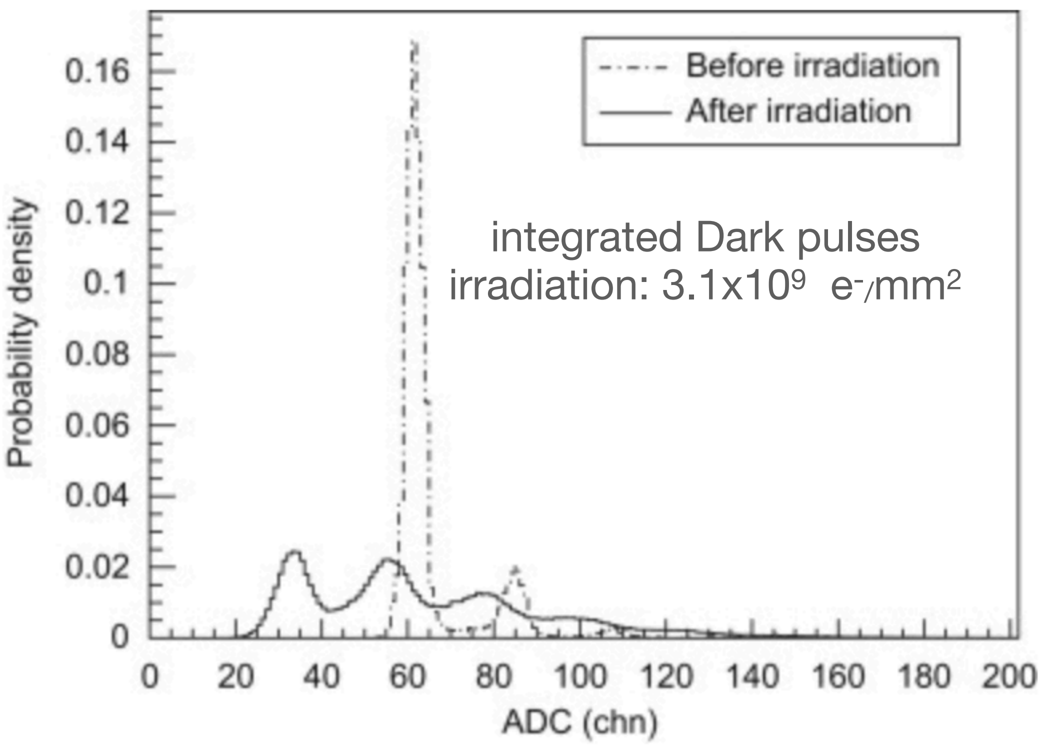
Radiation tolerance - Si PMs

https://doi.org/10.1016/j.nima.2009.01.176

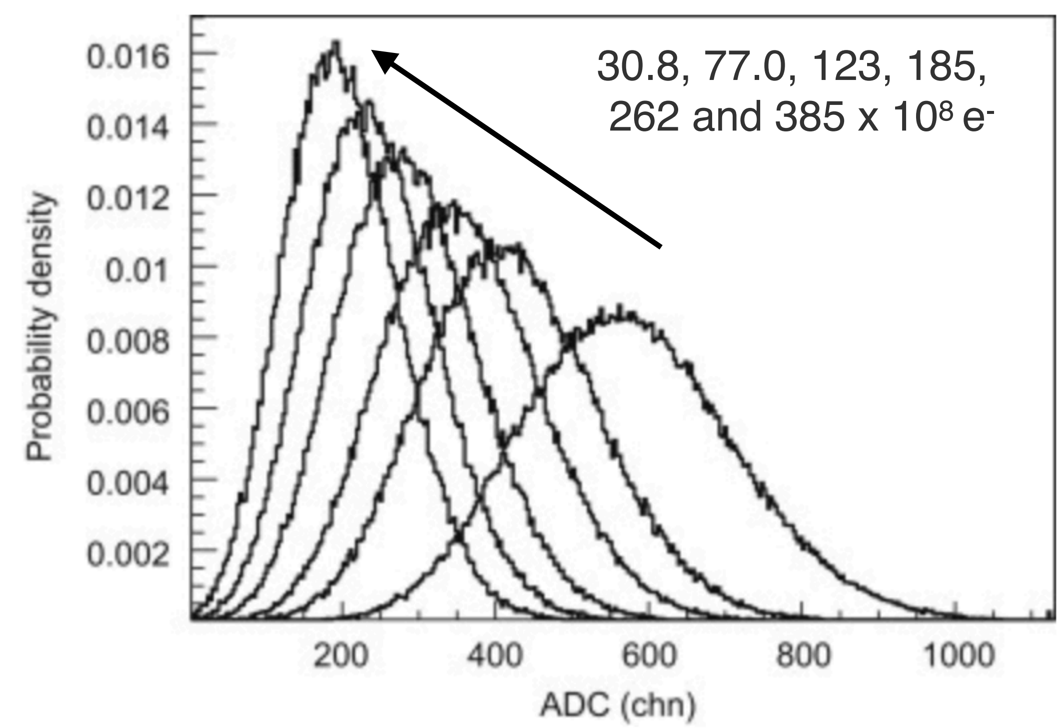
Noise and radiation damage in silicon photomultipliers exposed to electromagnetic and hadronic radiation

S. Sánchez Majos, P. Achenbach, C. Ayerbe Gayoso, J.C. Bernauer, R. Böhm, M.O. Distler, M. Gómez Rodríguez de la Paz, H. Merkel, U. Müller, L. Nungesser, J. Pochodzalla, B.S. Schlimme, Th. Walcher, M. Weinriefer, C.J. Yoon

- Si PMs are less radiation hard than gaseous PMT
- electrons: both bulk and surface damage
- found paper on Si PMT irradiation with 14MeV electrons



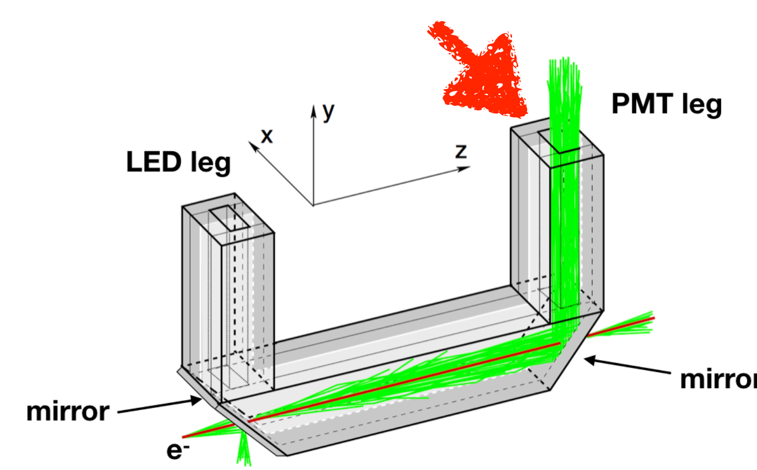
increase in dark count rate



reduction of photon efficiency / gain

Our PMTs sit quite a bit away from the main line
→ check dose levels in MC!

Probably need to put shielding around!



Summary

The Helium issue & SiPMTs:

- Helium Cerenkov medium in connection with gaseous PMT problematic:
  Helium diffusion through window breaks PMT
  also difficult wrt gas tightness
- alternative: Argon (higher refractive index)
- Silicon PMTs (don't have the helium problem, also some other advantages)
- don't need to change our channel dimension in x, but in y: 9x9mm (Brems) and 1x1 (Compton)
- gain is ~10^5-10^6, cannot reduce indefinitely (break-down)
- need additional measures to reduce light yield
  → Neutral density filter T=0.1%
  → possible to obtain same rate reduction as for measures before

Radiation tolerance:

- Gas volume (noble gas) should be insensitive to radiation, also can be exchanged
- check radiation levels at the site where PMTs sit → shielding needed also to collimate beam
- it's difficult to put a number to this…