Moller Detector Simulation

- Optimization of Quartz Radiator and Light-guide Geometries

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Recall: the last phone conference:

- A baseline design of the detector rings was developed in MC
- ~16-20 pe yield can be obtained from the baseline design
- Cross-talk / background issues were briefly discussed

What happened since then:

- Had an off-line discussion with KK and Michael
- KK provided updated CAD model drawings recently
- Implemented the CAD drawing of the detector design into MC
- Started to optimize the geometry of radiator & light guide

Design Considerations

1. Maximize light yield

- Preserve TIR in the quartz radiator
- Reduce photon escape from quartz to air
- Ease the export of photon from quartz to light-guide
- Reduce the number of photon bounces on light guide surface

2. Minimize background & cross-talk

- Minimize the shower effects
- Minimize Cerenkov and scintillation lights in air-core light guide

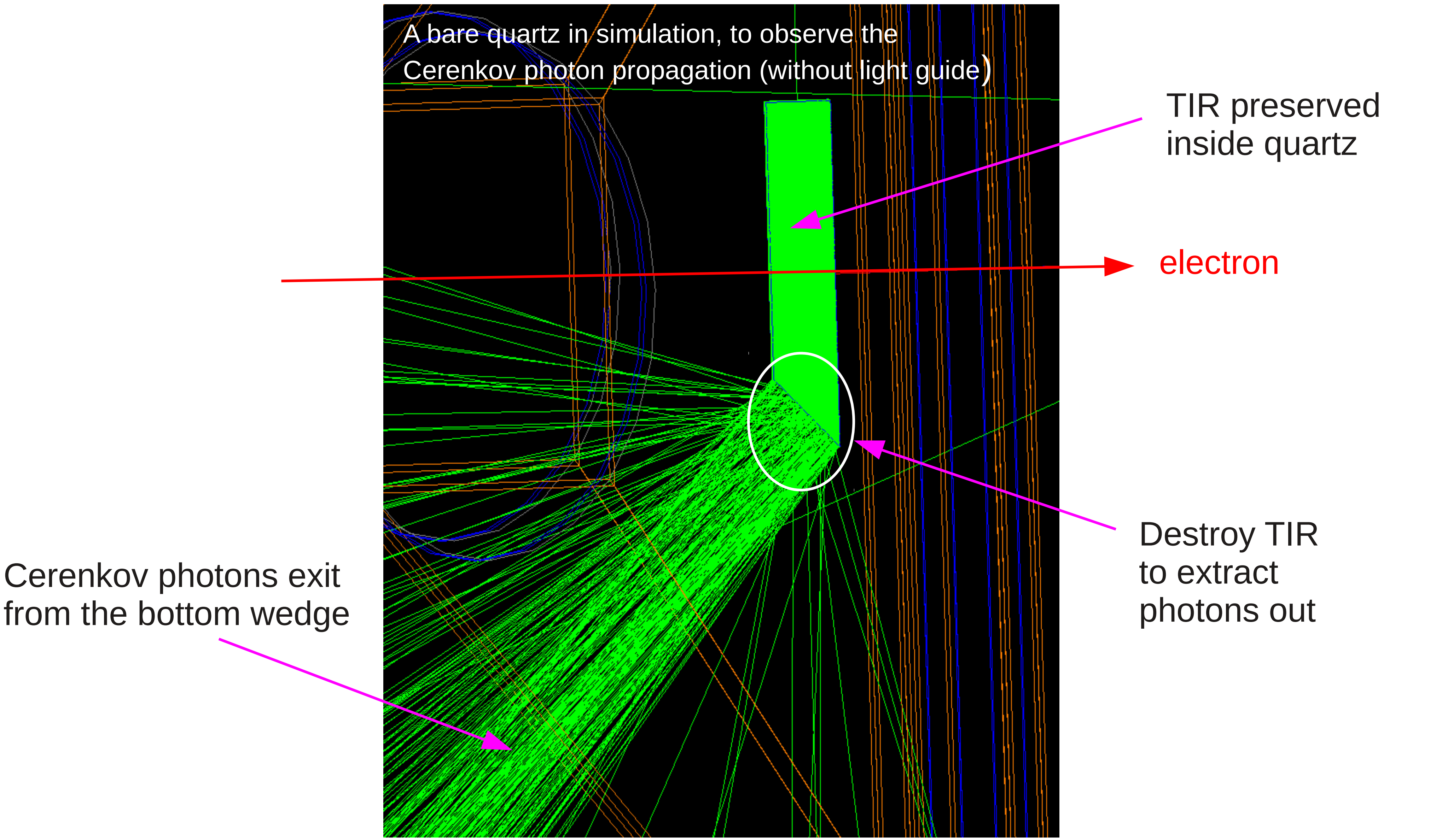
3. Simplify geometry to reduce cost, as well as engineering, installation and maintenance difficulties

Cerenkov and TIR angles of Quartz Radiator

refractive index	1.45	1.50	1.55	1.60
Cerenkov angle	46.3	48.1	49.8	51.3
TIR critical angle	43.6	41.8	40.1	38.6
tolerance to preserve TIR	2.8	6.4	9.6	12.6

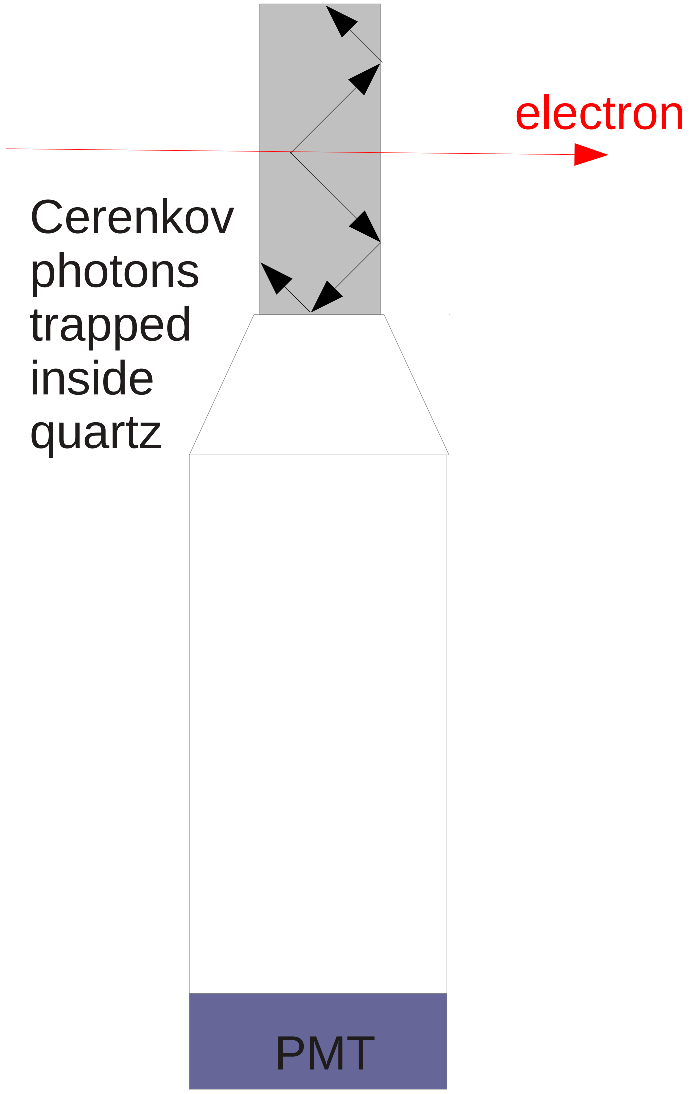
For the sake of simplicity, it would be safe to take 45 degree for the following 2D geometric optics analysis

Cerenkov Photon Propagation

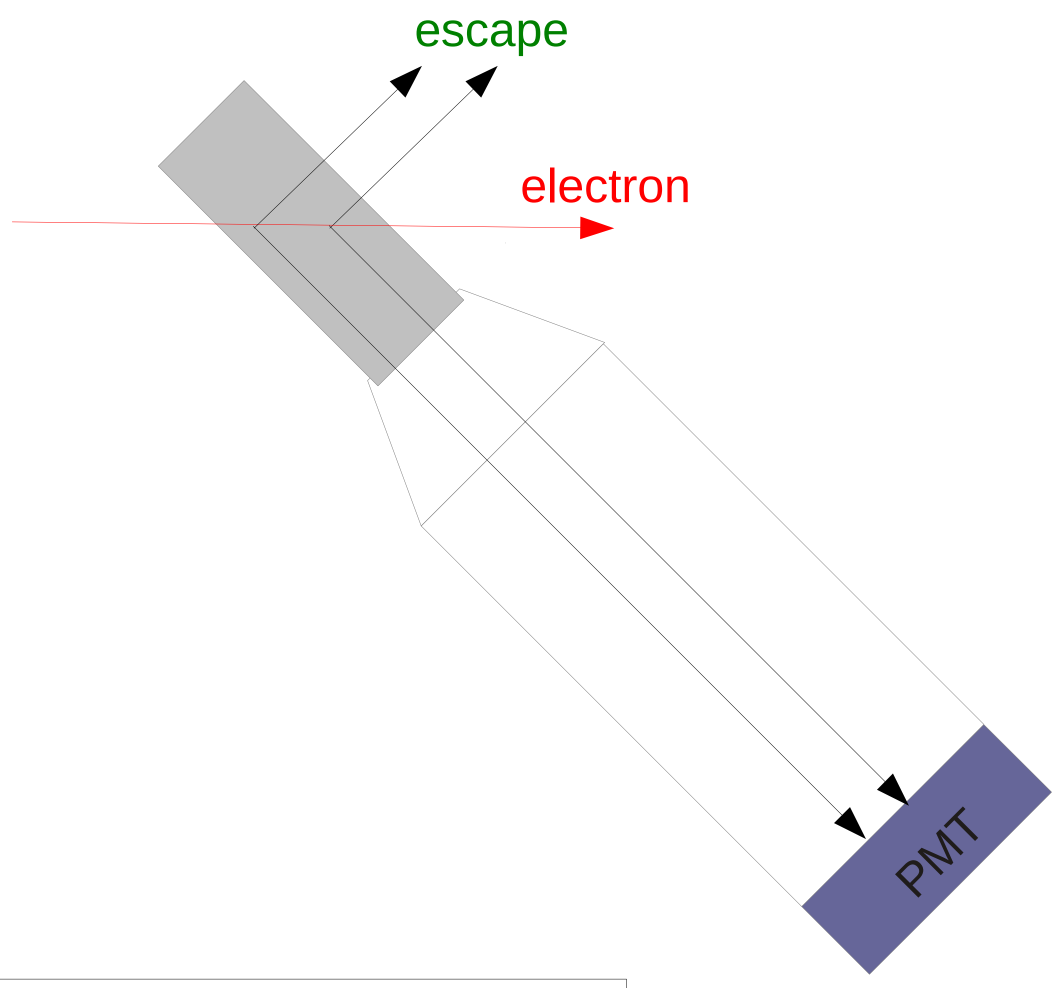


(Example detector models are discussed below)

Model 1

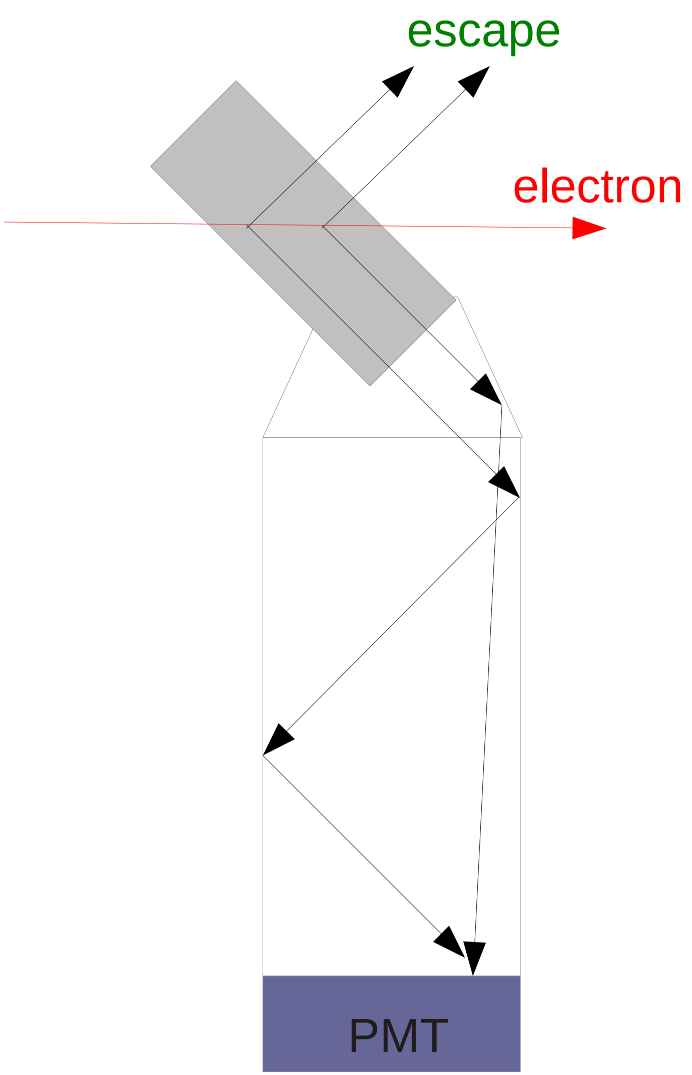


Model 2

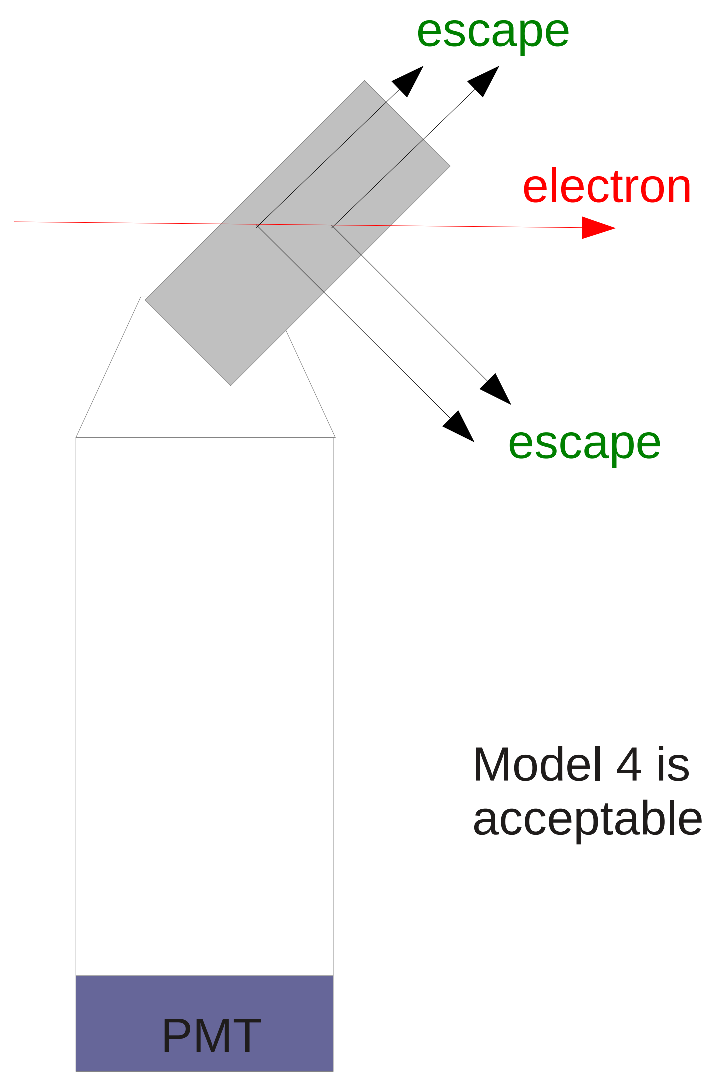


Black arrows indicate propagation of Cerenkov photons generated in quartz

Model 3

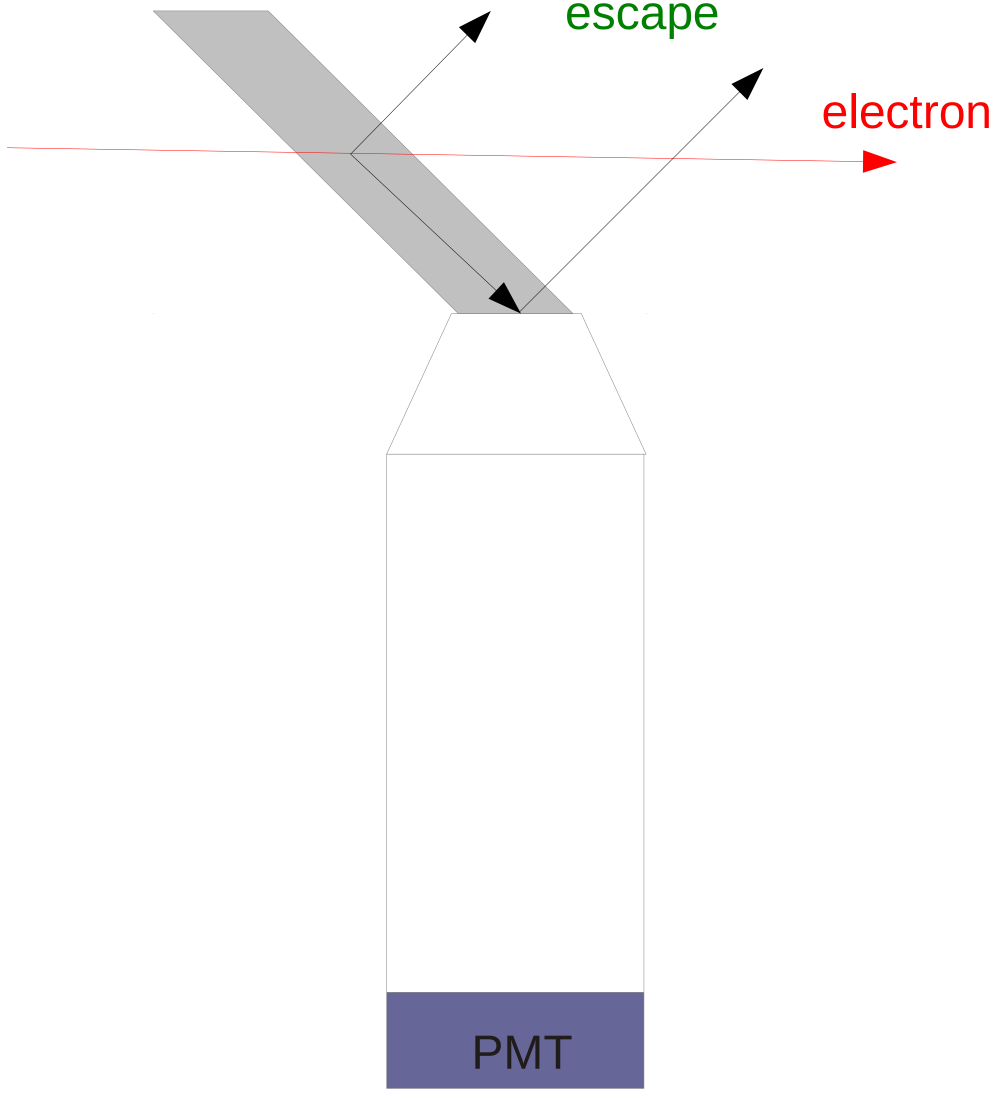


Model 4

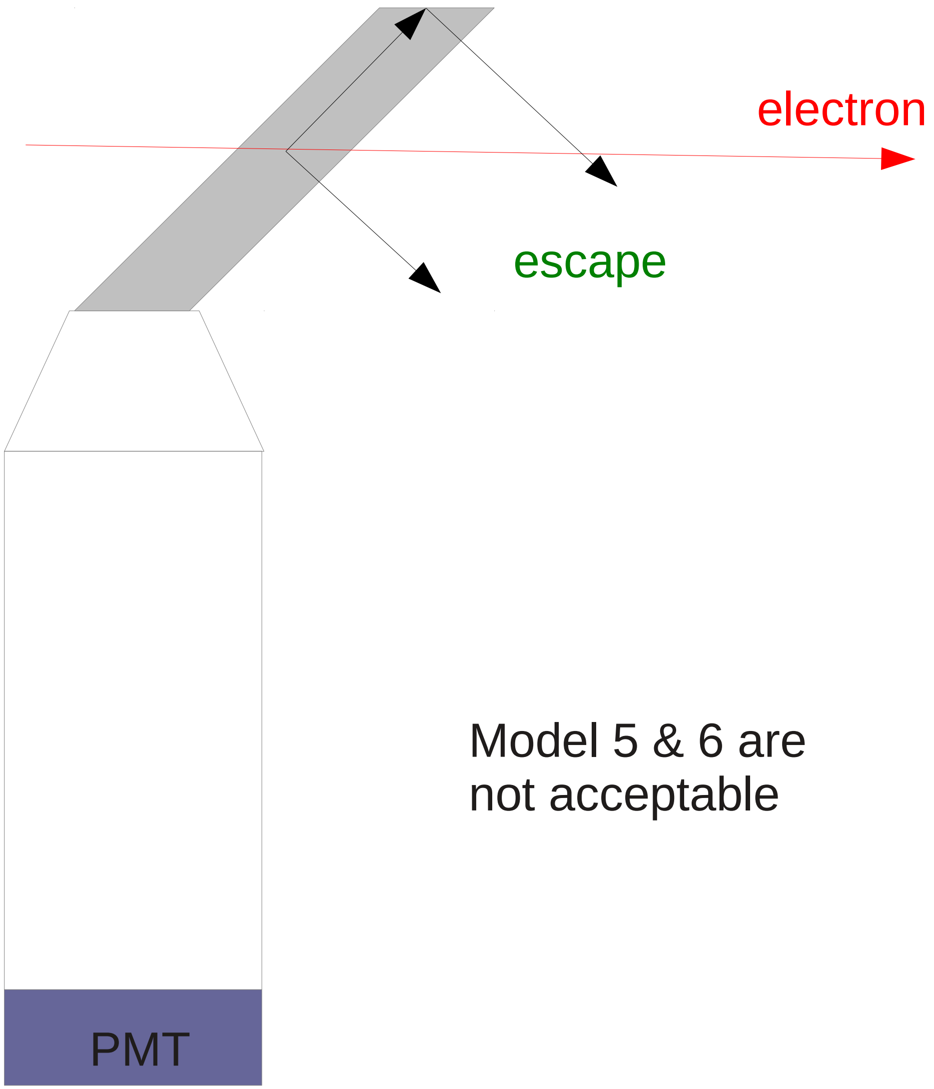


Model 4 is not acceptable

Model 5

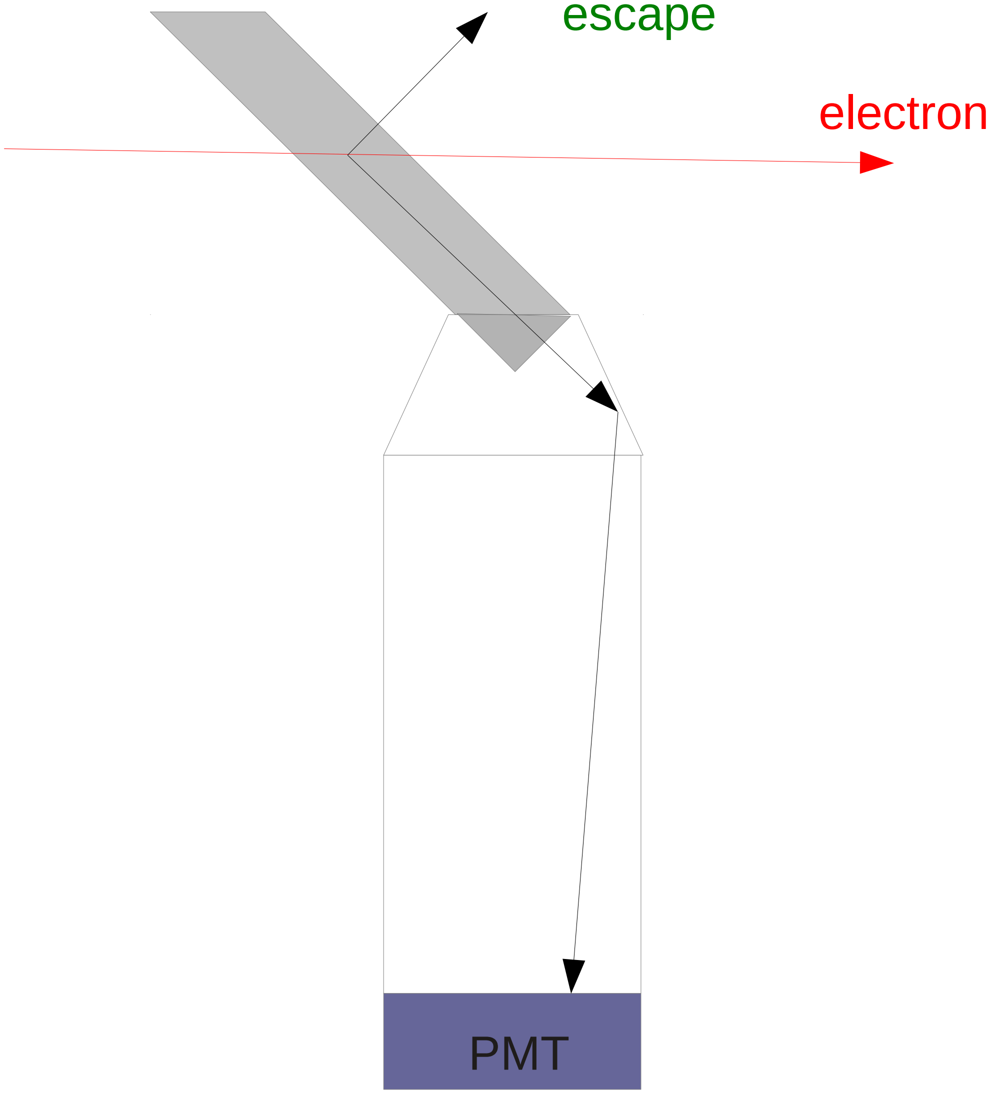


Model 6

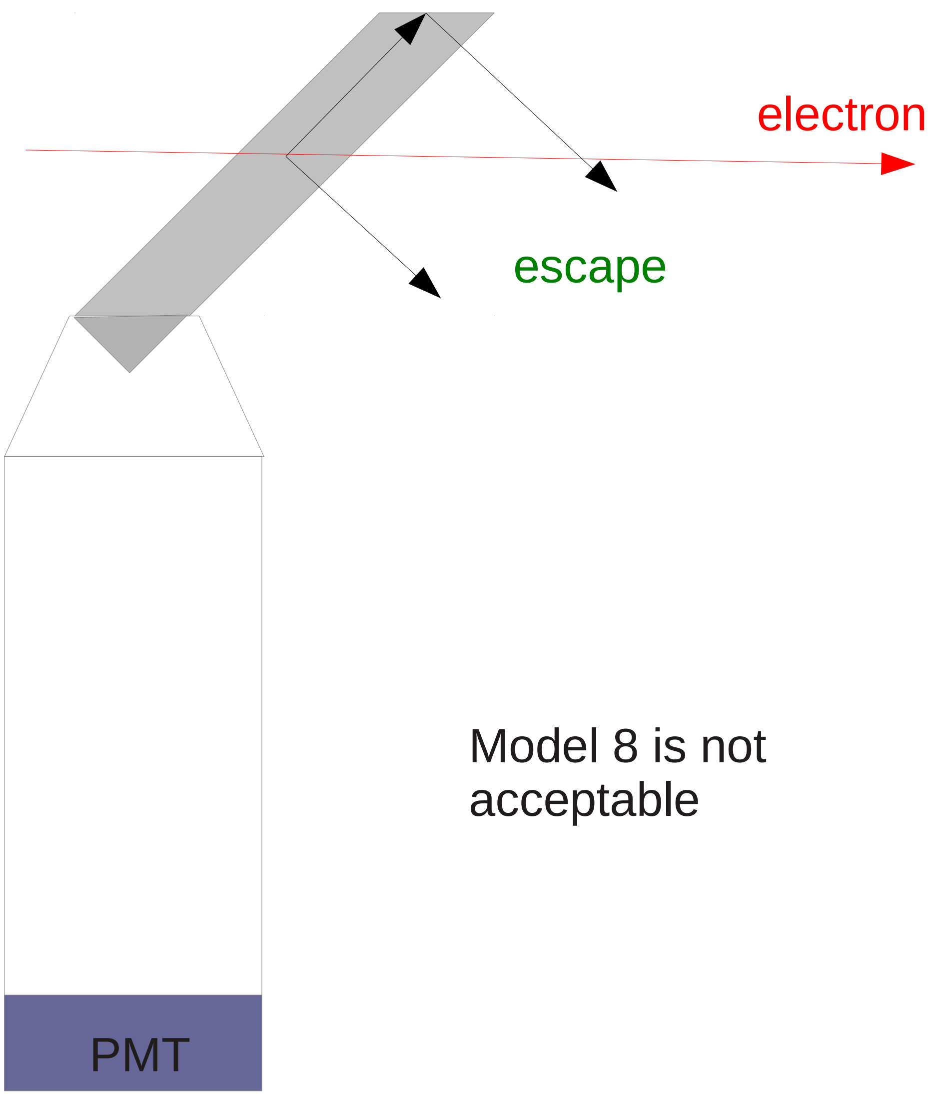


Model 5 & 6 are
not acceptable

Model 7

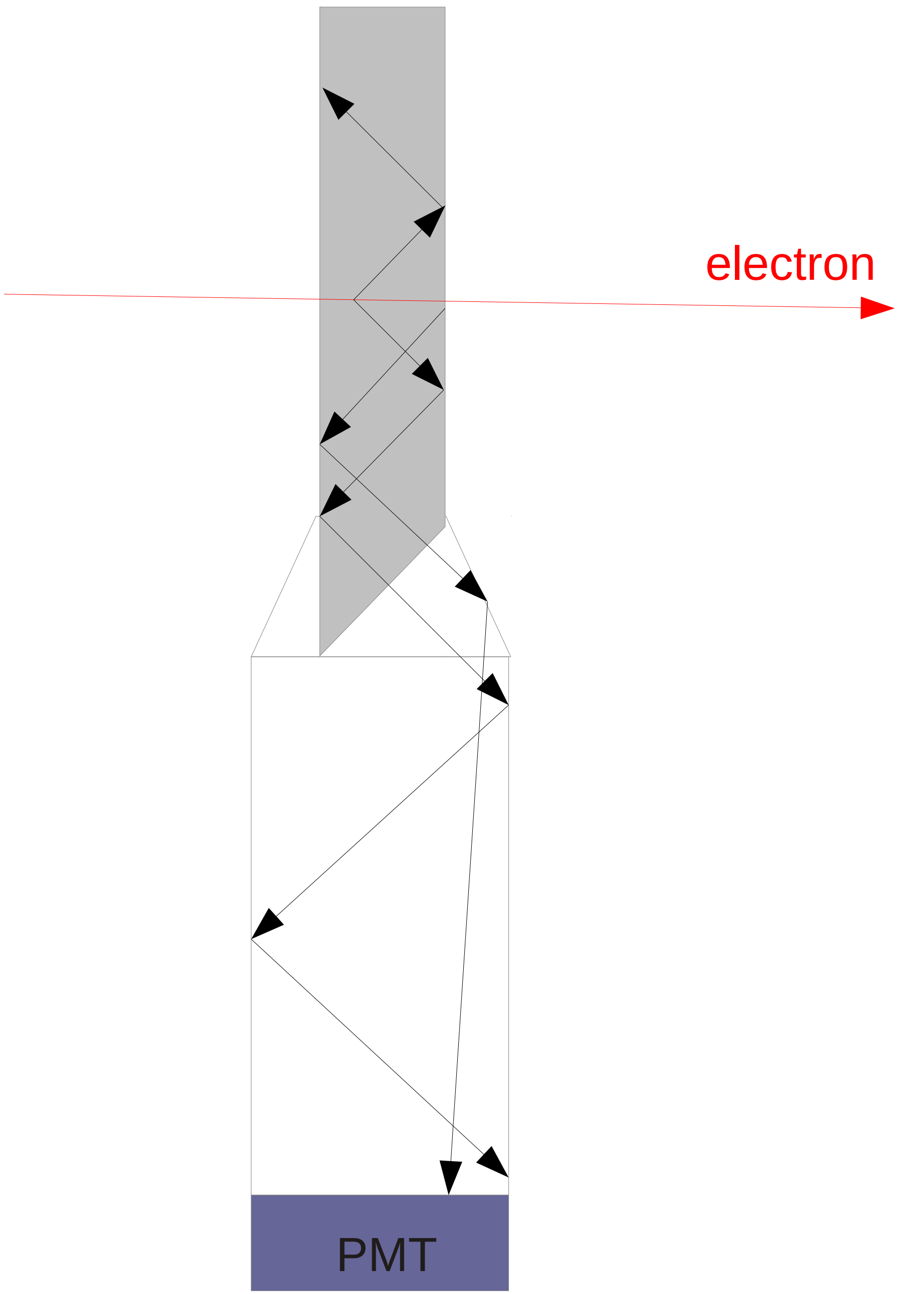


Model 8

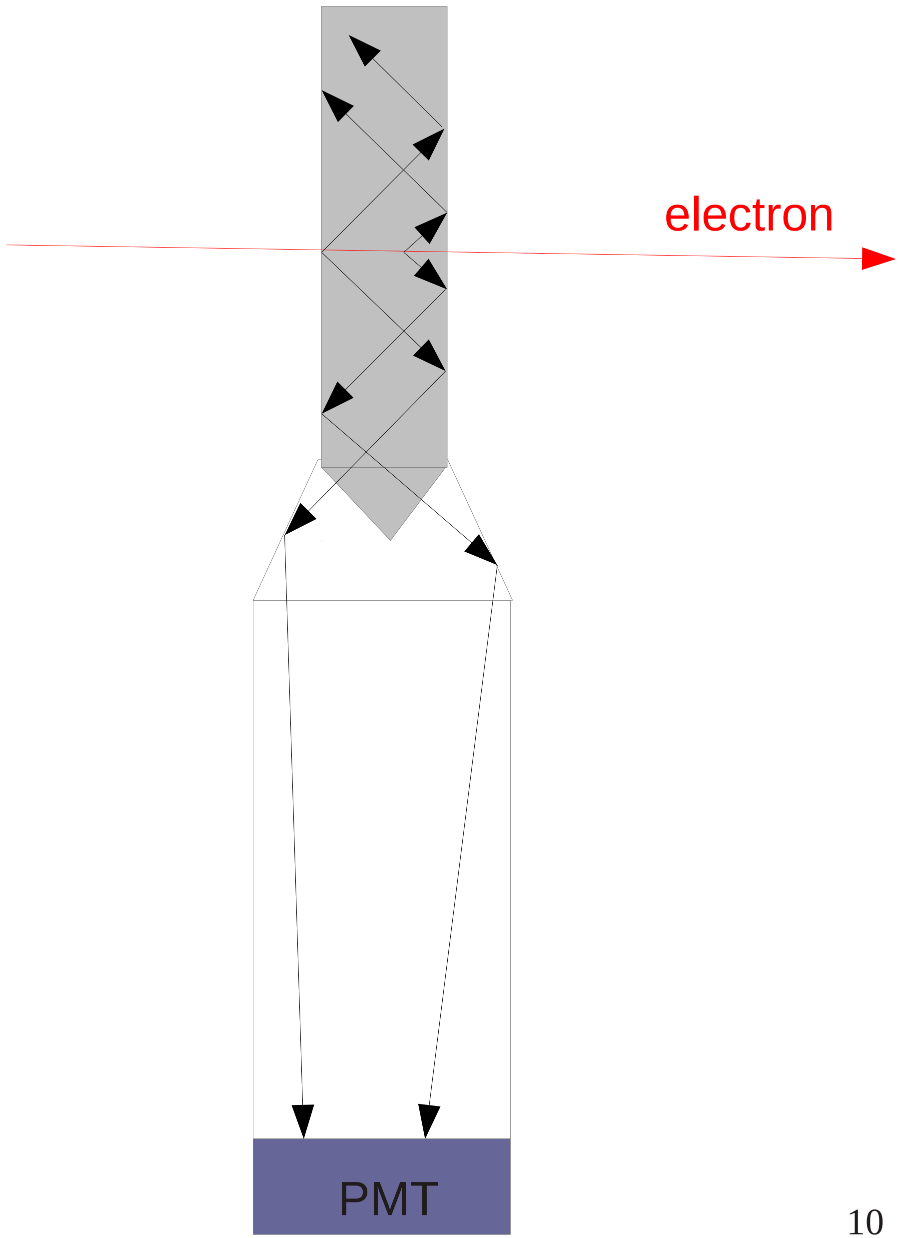


Model 8 is not acceptable

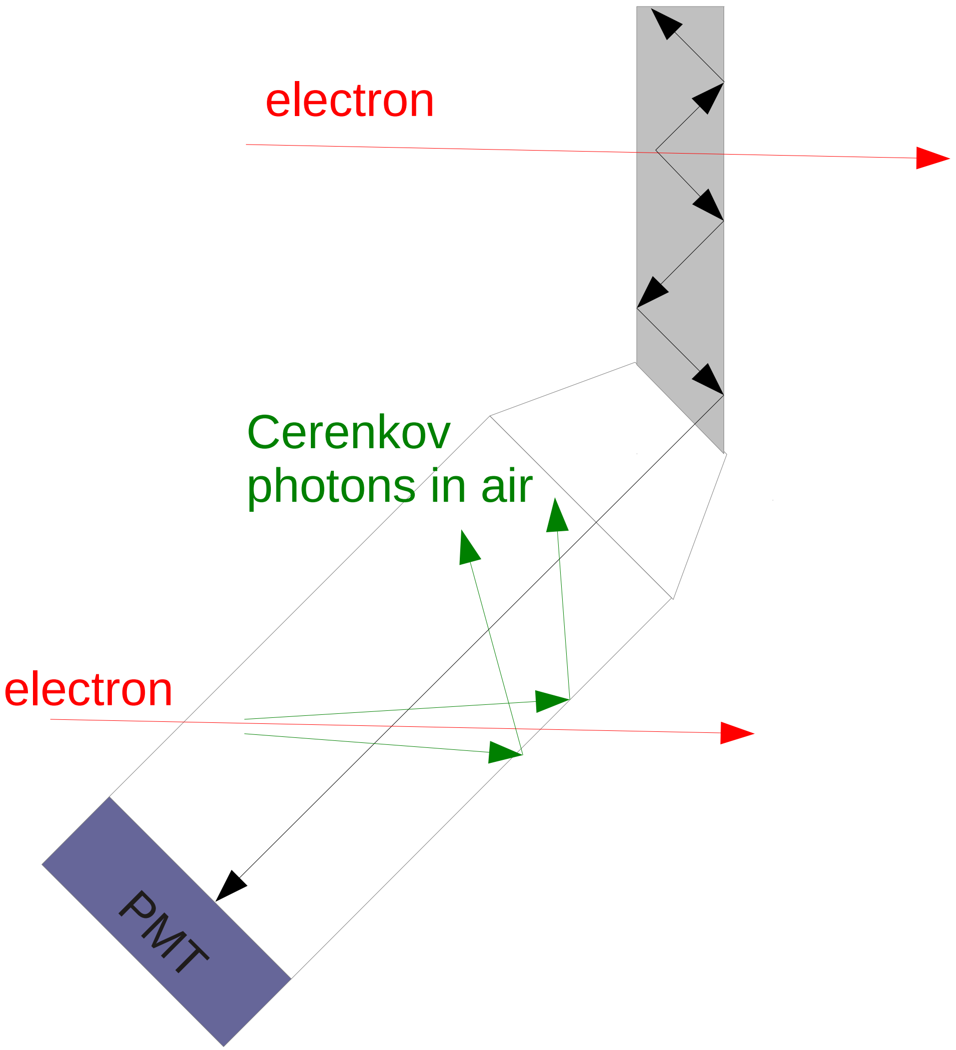
Model 9



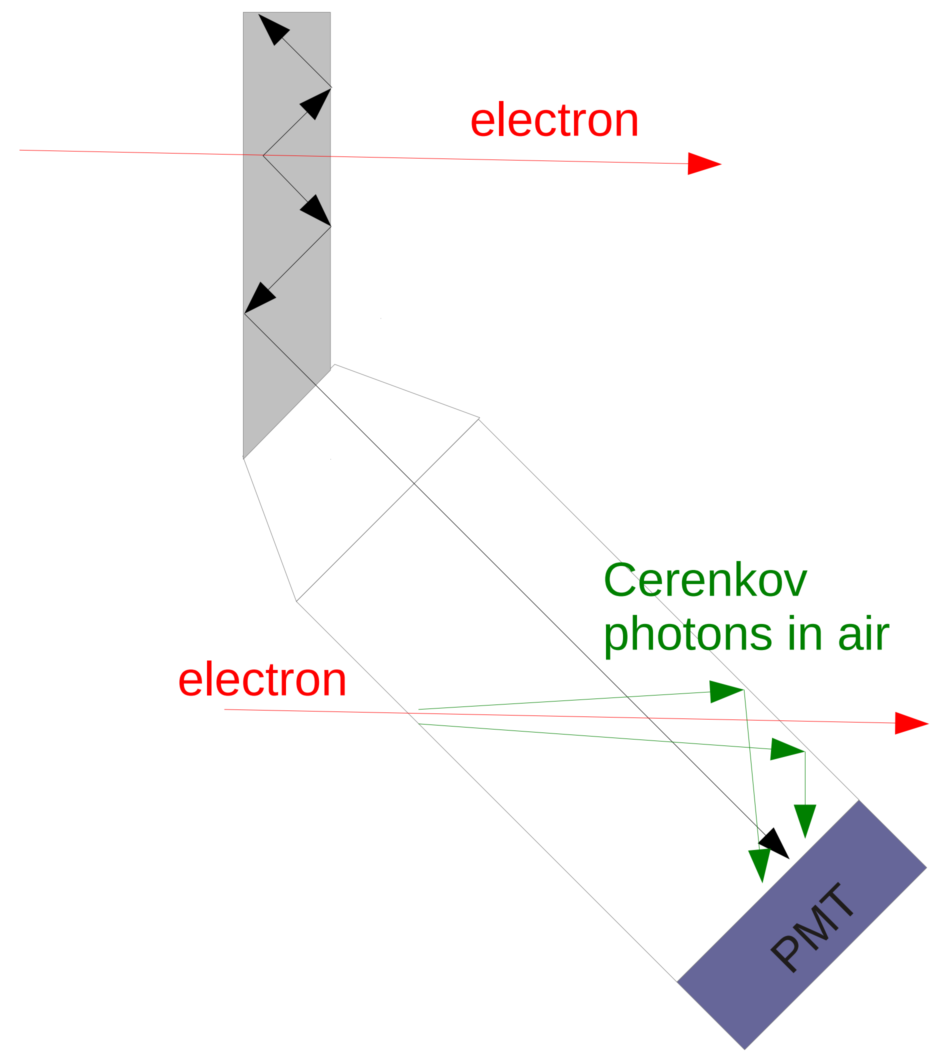
Model 10



Model 11



Model 12

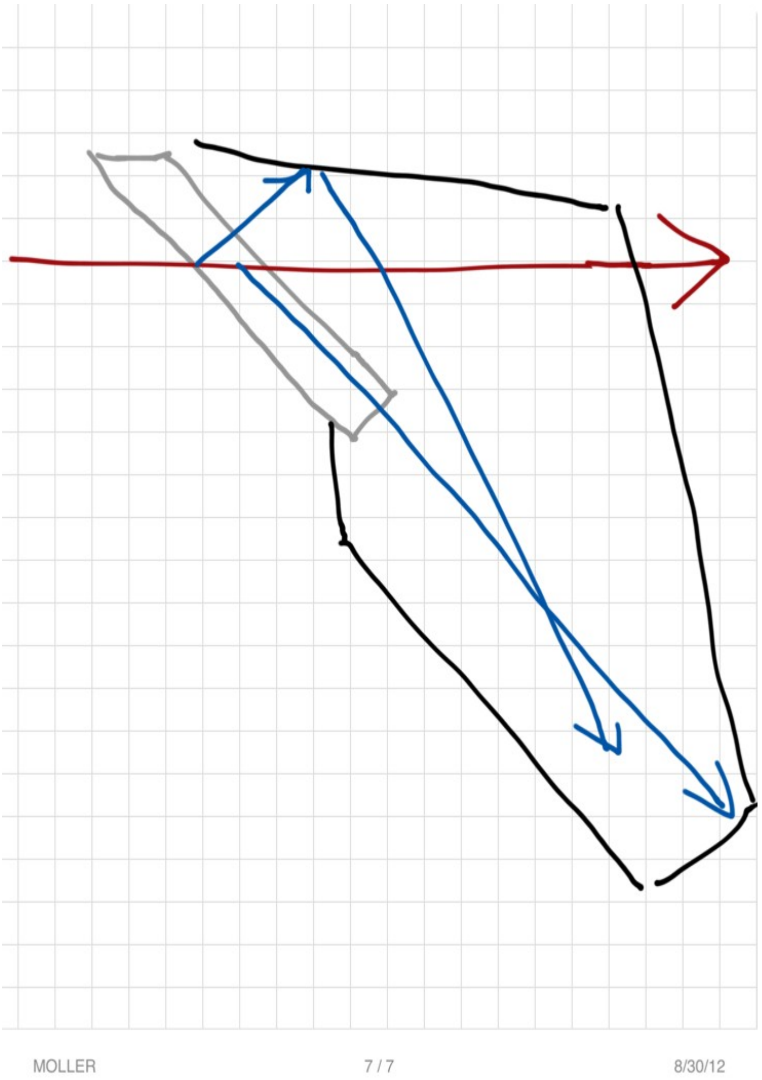


Model 10 has more background in light guide

Model 13

KK's model

(another version of model 2)



Model Selection

1. #PE yield

2. Engineering difficulty

3. Cerenkov background in air-core light guide

4. Cross-talk due to shower effects

5. Low-end #PE tail due edge effects (increasing RMS width)

6. High-end #PE tail due to shower in quartz
   (increasing RMS width, affected by the effective
   thickness of quartz)

Comparison of Models

(based on the simple geometric optics analysis)

Table 1

Model	#PE yield	Cerenkov background in air-core light guide	Cross-talk due to shower effects	Engineering difficulty	low-end #PE tail	high-end #PE tail	Rule-out?
1	medium	medium	medium	low	low	low	
2	medium	high	high	high	high	high	yes
3	medium	medium	medium	medium	high	high	
4	low	medium	medium	medium	high	high	yes
5	low	medium	medium	medium	low	high	yes
6	low	medium	medium	medium	low	high	yes
7	medium	medium	medium	medium	medium	high	
8	low	medium	medium	medium	medium	high	yes
9	high	medium	medium	low	high	low	
10	high	medium	medium	low	medium	low	
11	high	low	low	high	high	low	yes
12	high	high	high	high	high	low	yes
13	high	high	high	high	medium	high	yes

"red" indicate the rule-out reasons

Implementation in Simulation

1. Used the new CAD drawings as reference

2. Changes w.r.t the 1st version baseline design:

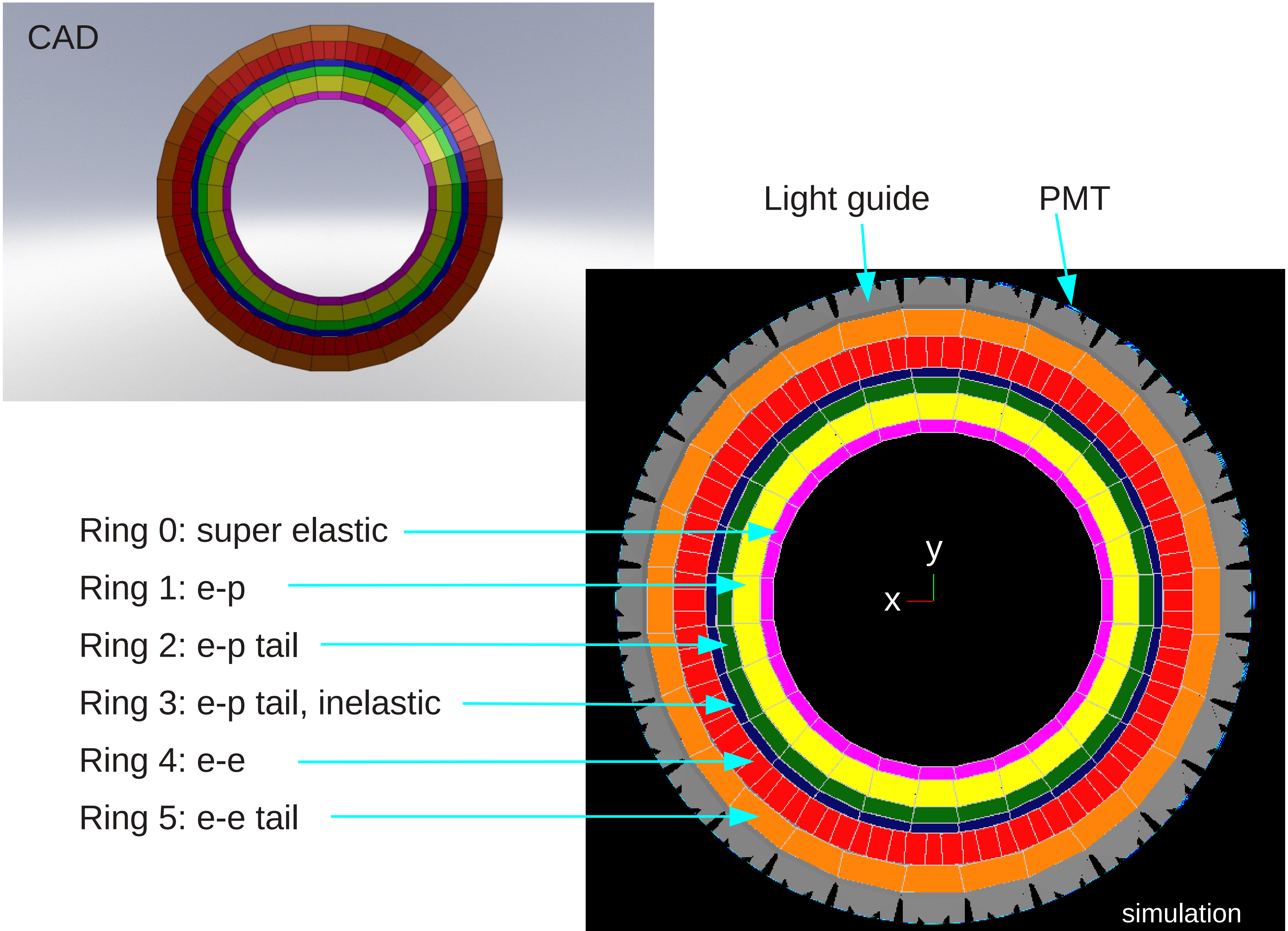
- Quartz on e-e ring was further azimuthally segmented into 3
- Quartz on e-p tail ring was radially segmented into 2
- Quartz's shape (beam's eye view) was changed from box to trapezoid
- Quartz thickness was changed from 2 cm to 1 cm
- Quartz were staggered to have some overlap between neighbours

3. Used 3 inch PMT,
   quartz was wrapped with reflection material,
   no shower-max detector yet

4. Focused on Models 1, 3, 7, 9, 10

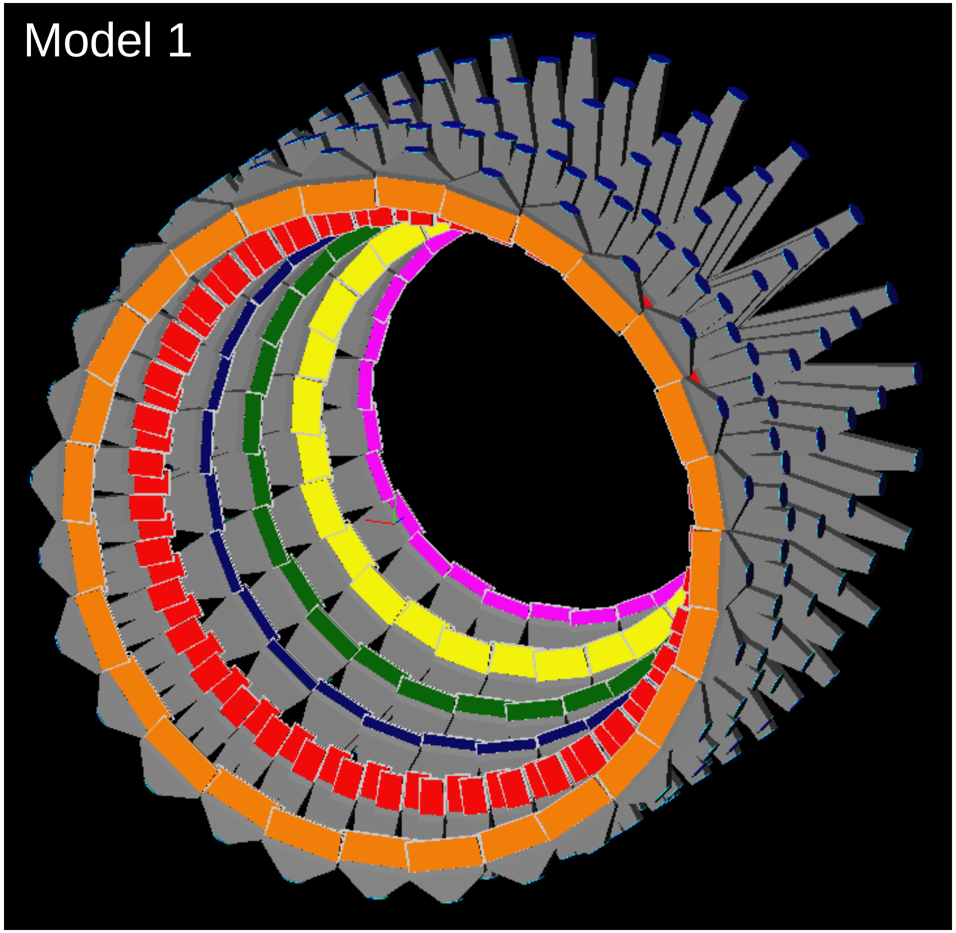
5. Model 11 was also tested to see the possible maximum #PE

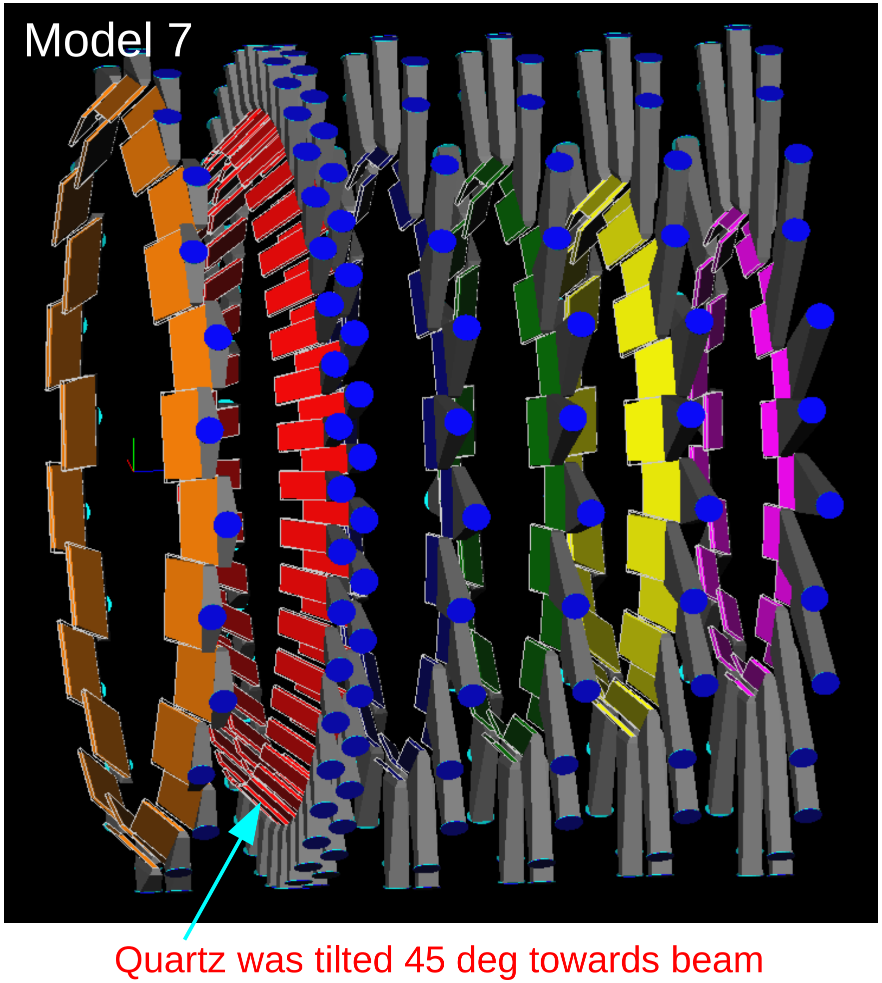
Implementation in Simulation



Implementation in Simulation

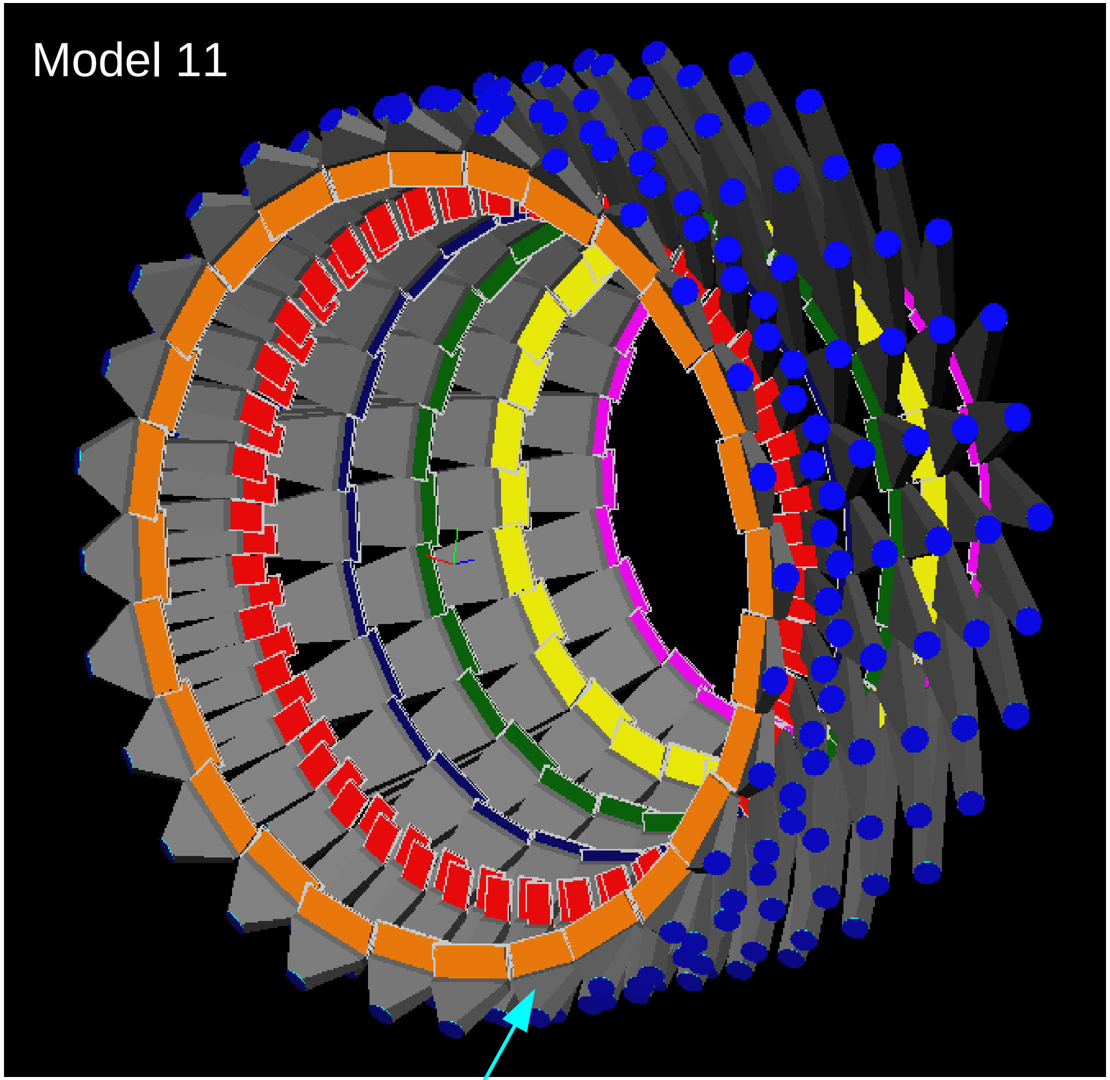
Model 1 is the baseline design
Model 7 is the design from proposal





All models except model 13 were tested in simulation

Example: Pros & Cons of Model 11



Light guides were tilted 45 deg towards beam

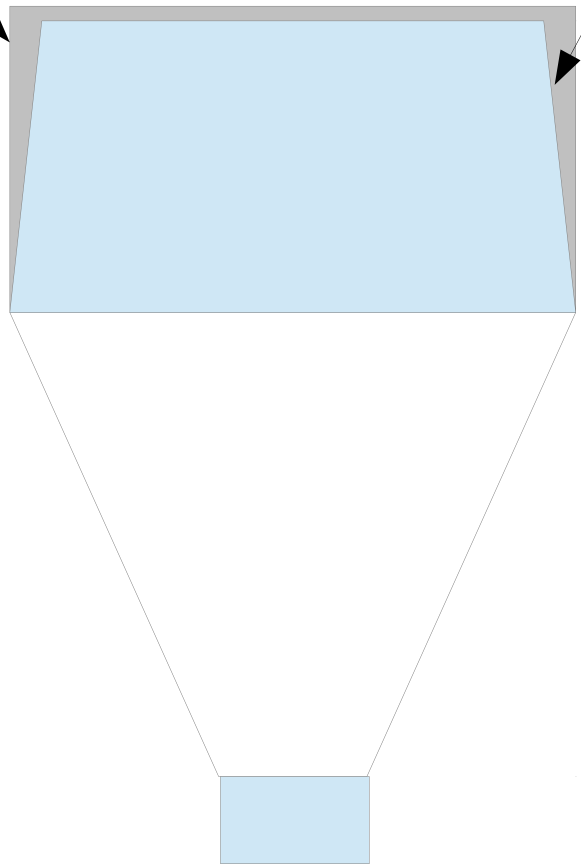
Pros:

- it preserves TIR;
- no escape of Cerenkov photons from quartz to air;
- its light guide match the Cerenkov angle, reducing bounces of photon on light guide inner surface;
- PMT located upstream of quartz radiator receives minimum shower events;
- Cerenkov light generated in air-core light guide hardly propagate to PMT.

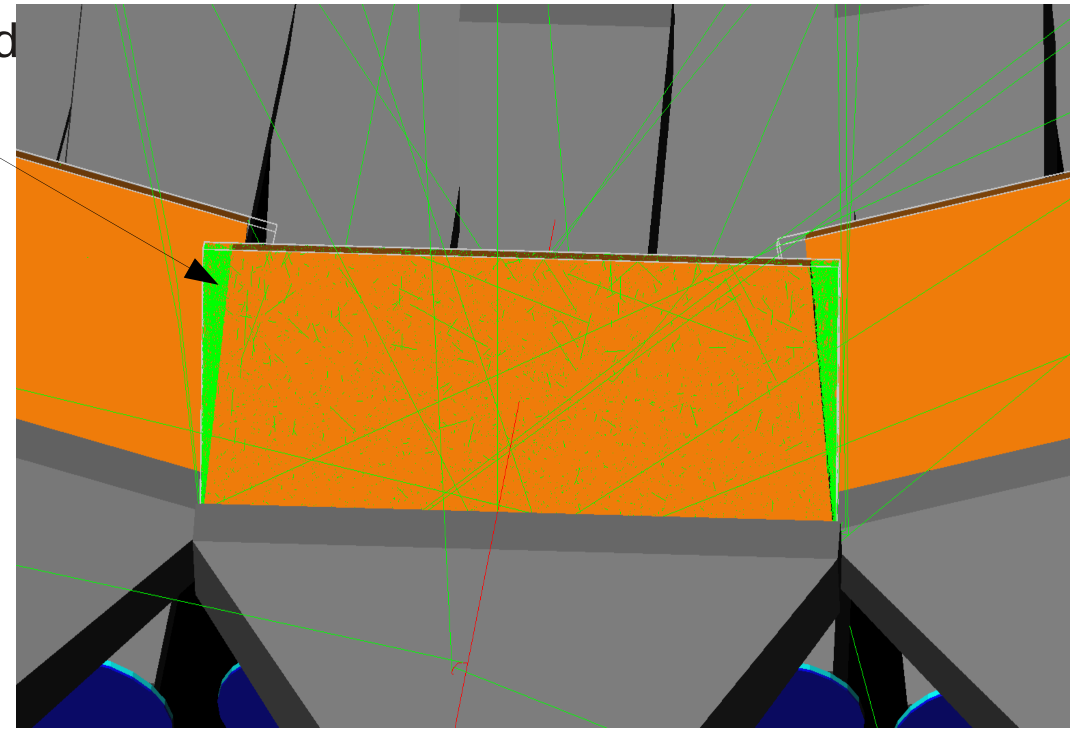
Cons:

- Long light guide could increase bounces of photon
- Tilting light guide increases the engineering difficulties.

Quartz Housing



Beam's eye view
(trapezoid quartz)



Quartz housing/wrapper:

- Thin film (reduce shower)
- High reflectivity (collect the escaped photons)
- Light tight
- rad-hard

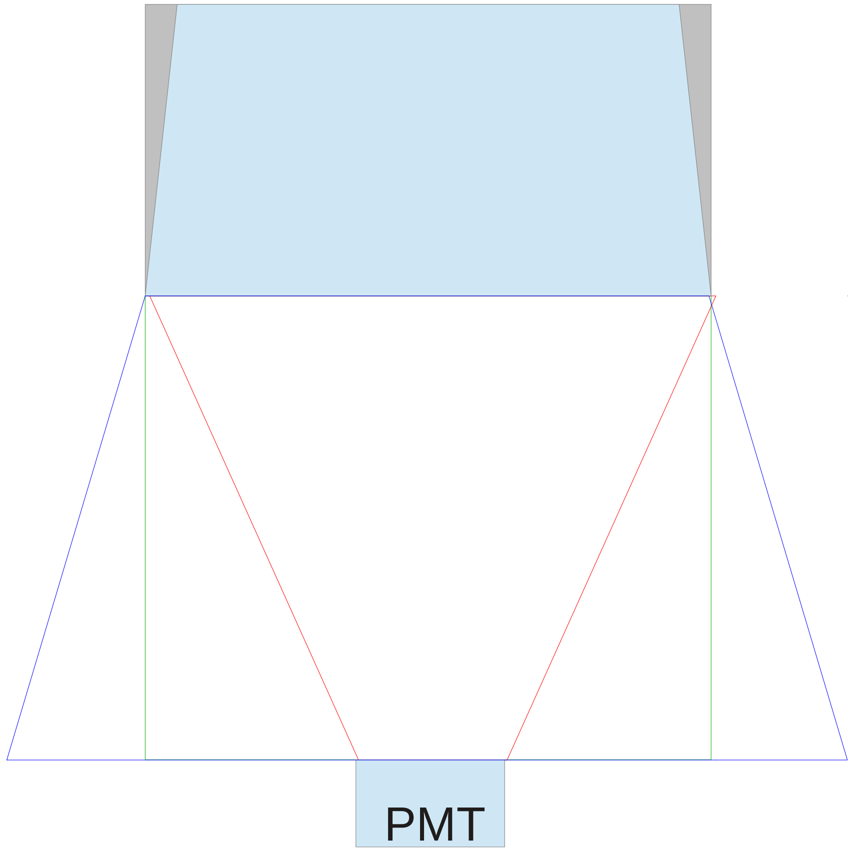
#PE Yield

Table 2 *(MollerDet Simulation r 224)*

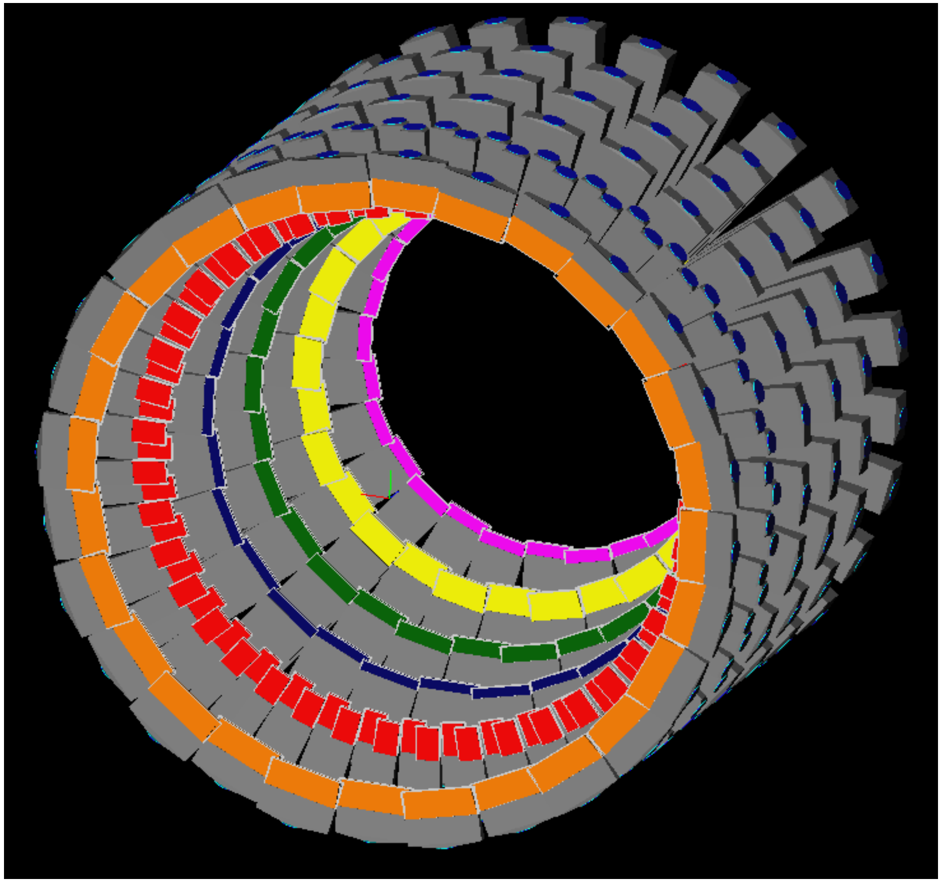
Model	Ring 0 super-elastic	Ring 1 e-p	Ring 2 e-p tail	Ring 3 e-p tail inelastic	Ring 4 e-e	Ring 5 e-e tail	
1	16.8	22.9	19.2	17.3	23.2	13.3	
RMS	4.4	6.2	5.5	5.6	6.8	3.7	
3	12.2	10.5	11.4	11.8	24.2	21.3	
RMS	4.7	5.1	4.3	4.9	5.8	7.3	
7	11.5	9.1	11.8	12.7	26.9	17.3	
RMS	4.3	3.7	4.5	6.2	6.8	6.5	
9	12.2	11.5	10.8	12.4	29.3	24.8	
RMS	4.0	4.3	4.0	3.7	8.6	6.9	
10	12.8	12.1	12.8	13.4	30.3	24.2	preferred
RMS	4.5	3.5	3.8	4.1	7.3	7.0	
11	12.9	12.7	13.4	13.9	31.5	21.2	
RMS	4.6	3.5	4.1	4.3	6.0	4.6	

Light Guide Shape from Beam's Eye View

Need simulations to determine which geometry
(e.g. red, green or even blue) can maximize #PE



Beam's view



implementation of box-shaped light guides

Effects of Variations

Table 3

	Ring 0 super-elastic	Ring 1 e-p	Ring 2 e-p tail	Ring 3 e-p tail inelastic	Ring 4 e-e	Ring 5 e-e tail
Model 10 With 3” PMT and trapezoid light guide	12.8	12.1	12.8	13.4	29.7	24.2
Model 10 with 3” PMT and box-shaped light guide	9.1	10.8	12.8	16.23	31.2	21.1
Model 10 with 5” PMT	25.3	24.0	21.0	22.2	58.5	42.5
Model 10 with 5” PMT, but removed wrapping materials of quartz	19.5	21.4	17.0	18.5	51.8	33.3

Benefits of using large PMT and wrapping quartz can be clearly seen!

Conclusion

- By looking at table 1 and 2, Model 10 might be the most preferable model because of its:
  simplicity,
  high light yield,
  small edge and shower effects

- The #PE yield of detectors on e-e ring is ~ 30, with an excess noise of ~ 2.9% (promising!)

- Light collection (#PE) can be effectively improved by using larger sized PMT.
  e.g. light yield is doubled when PMT's size is changed from 3” to 5”

- Good quartz housing/wrapper can collect the escaped photons and increase light yield by ~10-20%

To-do: stick with one model (model 10?), and do more detailed optimization