PVDIS simulations

June 2018 SoLID Collaboration Meeting

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Brief overview only, for details see DocDB:

- LGC background reduction
  - lgc bg 10-2017.pdf [SoLID Document 84-v1, report]

- LGC gas and glass background rates
  - PVDIS LGC background.pdf [SoLID Document 87-v1, simulation meeting slides]
  - lgc-bg-rates-01-2018 [SoLID Document 88-v3, report]

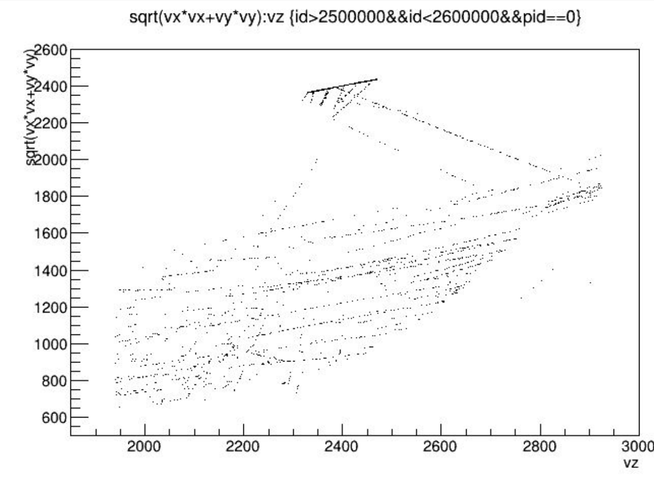
- No hole baffles
  - no hole baffles.pdf [SoLID Document 92-v1, simulation meeting slides]
  - forthcoming report

- Dalitz electrons
  - Dalitz electrons in PVDIS.pdf [SoLID Document 92-v1, simulation meeting slides]

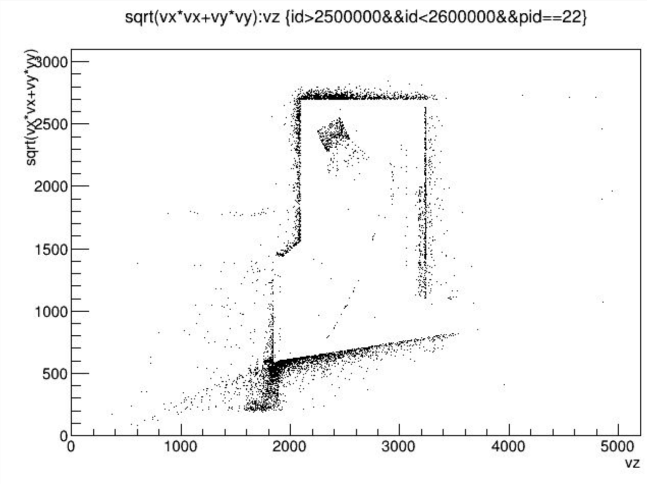
LGC backgrounds

Gas and glass backgrounds

- **Gas:** Charged tracks in tank radiate (mostly e^-/e^+ coming from ~direction of target)
- **Glass:** Charged tracks in PMT windows radiate (mostly created by photons coming from all directions, often from n capture or n inelastics)



Gas



Glass

Gas vs. glass rates

2x2 coincidences can be random (photons from two different primaries overlapping in time) or correlated (photons from a single primary).

Coincidence rate is strongly dominated by correlated gas coincidences, mainly from π^0.

Harder to simulate glass background is 2 orders of magnitude smaller.

	Singles		Random coincidence rate	Correlated coincidences	
	# PMTs per 3*10^6 pions	Rate (kHz/PMT)	(kHz/sector)	# Sectors per 3*10^6 pions	Rate (kHz/sector)
Sum π					
PMTs with glass hit signals	196	20	1	9	9
PMTs with gas hit signals	1863	190	78	996	915

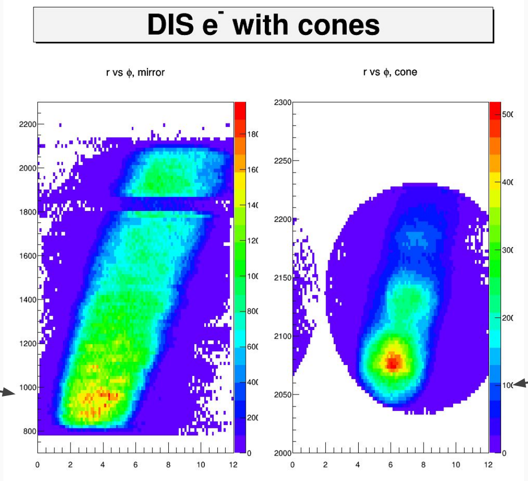
Electron trajectories

High x DIS electrons vs π^0 backgrounds:

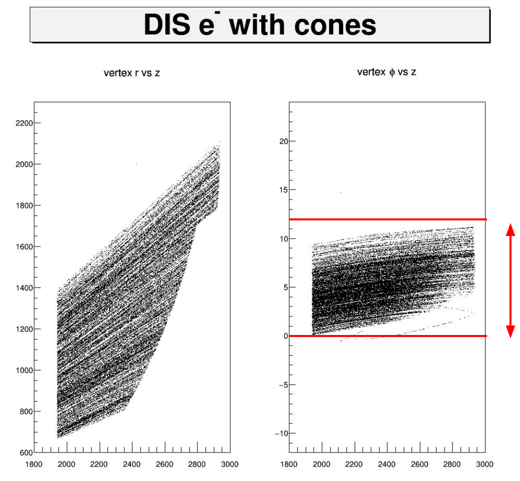
- Less filling of mirror
- Less filling of cone aperture
- More alignment in ϕ vs z
- Trajectories stay within sector

- More filling of mirror
- More filling of cone aperture
- Less alignment in ϕ vs z
- Trajectories cross sectors

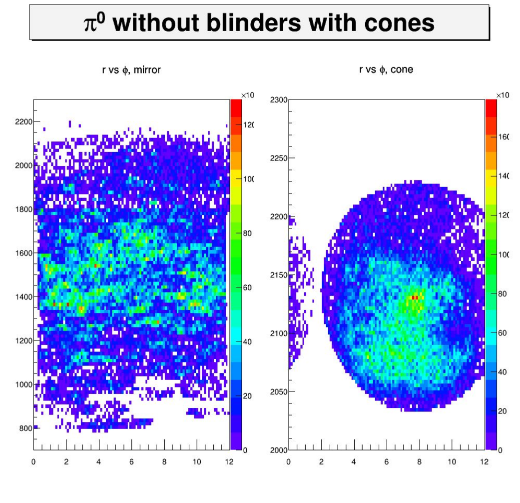
Photon positions at mirror



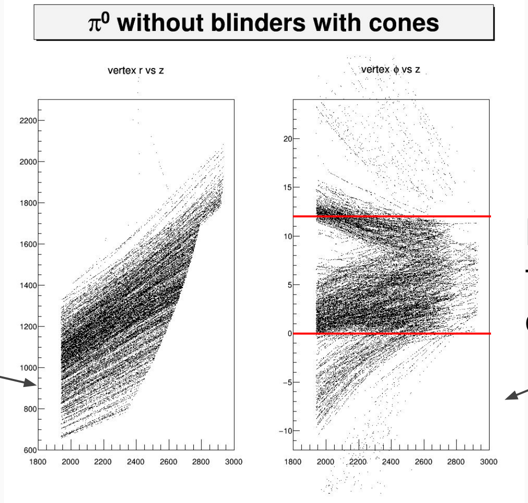
Photon positions at Winston cone



12° sector



Electron trajectories, r vs z



Electron trajectories, ϕ vs z

LGC modifications

- Adding optical blinders between sectors reduces 2x2 coincidences from π^0 photons by ~50%, no effect on DIS coincidences
- Removing cones reduces π^0 photon coincidences by ~50%, DIS coincidences by ~10%
- These background reductions are orthogonal; ~70% reduction in π^0 photon coincidences with blinders and no cones
- Effect of mirror masking has not been determined quantitatively, but appears not to be significant in combination with blinders and cone removal

“No hole” baffles

Baffle recommendation

"Recommendation 26: It should be confirmed that the baffle design, including the support structure, is optimized for background rejection and signal acceptance. Furthermore the baffle design should minimize generation of secondary backgrounds."

Baffle optimization work to date has been to study different materials, reduce background with "zigzag" design, optimize θ acceptance, and tune the BaBar/More1 baffle aperture to the CLEO field. However, altering the aperture has not been studied.

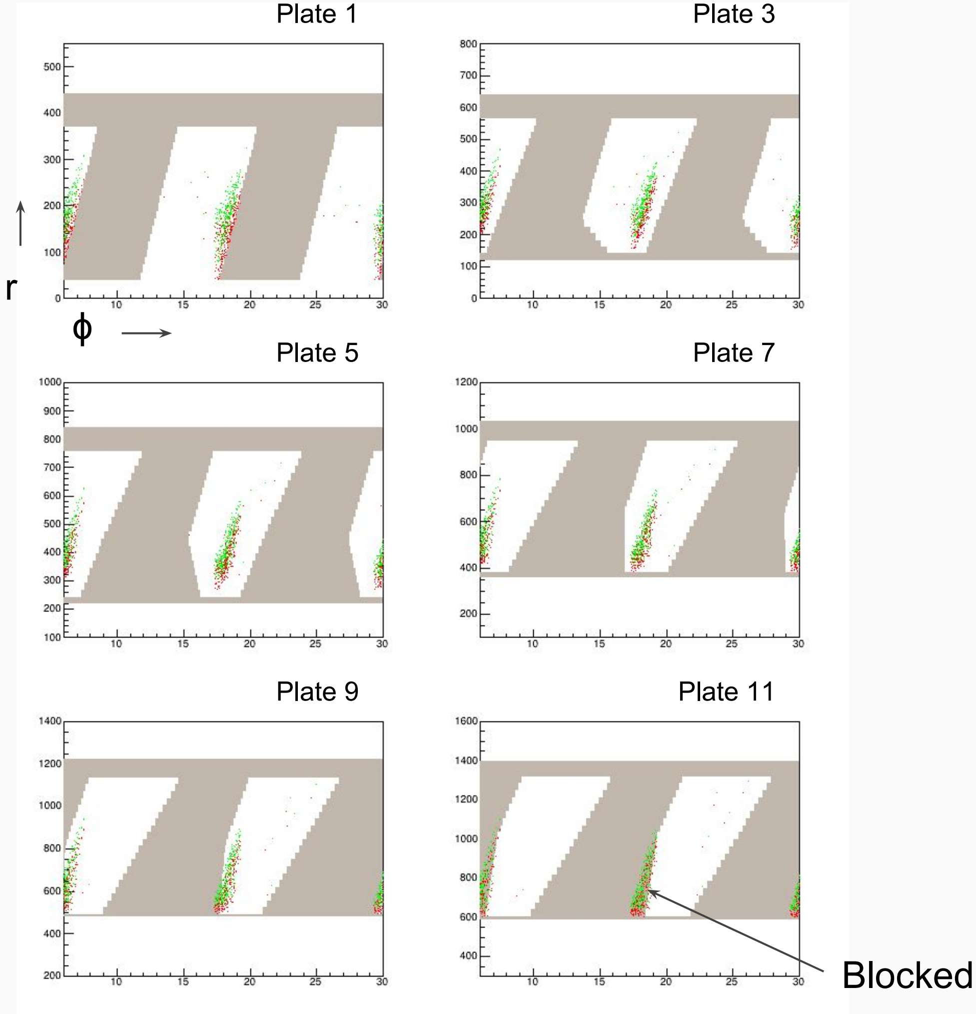
“No hole” baffles

The CLEO2 baffle design has some acceptance for photons coming from the z axis in the target.

Positions of these photons are shown superimposed on baffles modified to block these photons at the last plate.

This also blocks some DIS electrons (~20% below x=0.7). Other plates are modified to block these electrons upstream. Note photons are not blocked before the last plate.

Still some acceptance for photons from off axis.



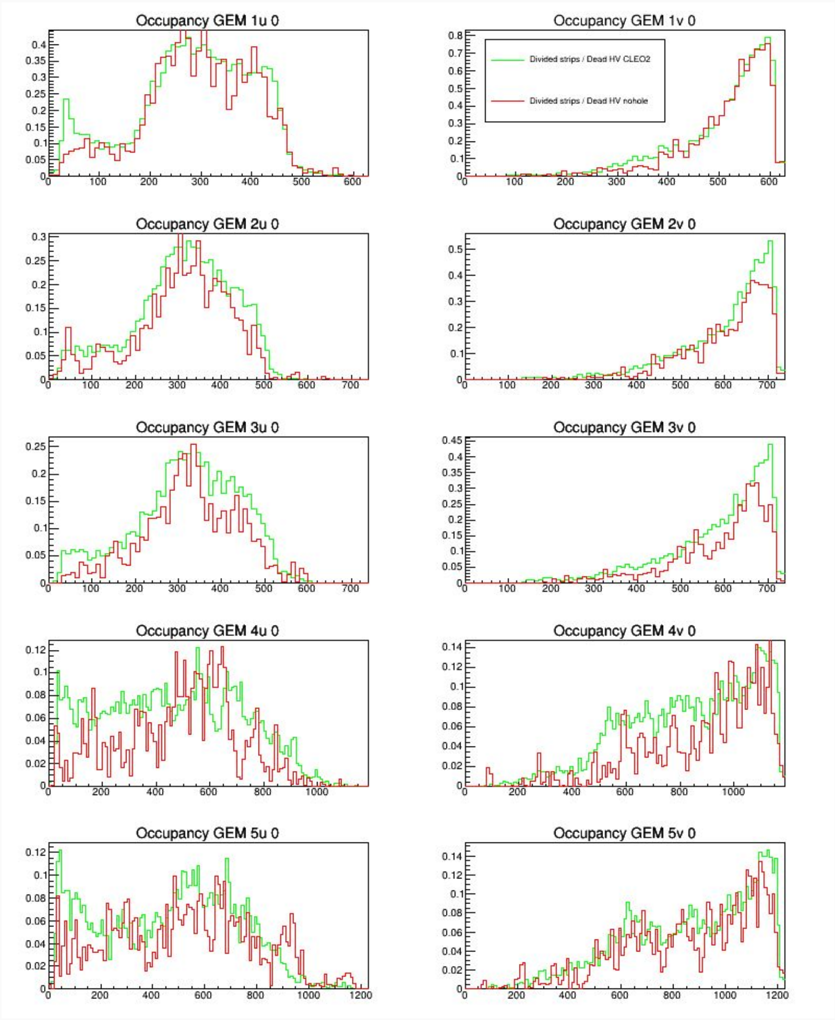
Findings

- “Hole” for on-axis photons can be closed with ~ 20% loss of DIS signal below x = 0.70 (at 50 μA).
- However, hole for off-axis photons remains mostly open.
- Hit rates for photons from target center into LGC are reduced about 70%. For photons from outer target, target wall, and downstream, rates are reduced ~20% to 40%.
- π^- and π^+ hit rates at EC are reduced about 20% and 35%.
- GEM occupancies are reduced a small amount.
- LGC 2x2 trigger rate is reduced by a factor of ~2; factor of ~10 in combination with LGC modifications.

GEM occupancy

Occupancies with no divided strips and no HV dead regions, for CLEO2 (green) and no hole (red) baffles, plotted vs. strip number in each plane (u, v) of each GEM.

No hole occupancies are lower but not dramatically so.



LGC 2x2 trigger rates

CLEO2

	Singles		Random coincidence rate	Correlated coincidences	
	# PMTs per 3*10^6 pions	Rate (kHz/PMT)	(kHz/sector)	# Sectors per 3*10^6 pions	Rate (kHz/sector)
			Sum π		
PMTs with glass hit signals	196	20	1	9	9
PMTs with gas hit signals	1863	190	78	996	915

No hole

	Singles		Random coincidence rate	Correlated coincidences	
	# PMTs per 3*10^6 pions	Rate (kHz/PMT)	(kHz/sector)	# Sectors per 3*10^6 pions	Rate (kHz/sector)
			Sum π		
PMTs with glass hit signals	157	16	1	6	6
PMTs with gas hit signals	869	89	17	452	416

Dominated by correlated coincidences in gas from π^0; 55% reduction

This reduction is orthogonal to LGC modifications… factor ~10x combined.

Summary

- Background in LGC is dominated by e^-/e^+ from π^0 radiating in the gas. Coincidences due to hits in PMT glass are ~100x lower rate.
- Gas coincidence rate can be reduced by factor ~4 with modifications to LGC design
- Baffle optimization: Small improvements in pion hit rates in EC and GEM occupancy. Factor of ~2 in LGC coincidence rate. Signal rate is down ~20% (at same beam current).
- Small effects of significant baffle change implies we are near optimum.

Extra

Dalitz electrons

Dalitz decay is $\pi^0 \rightarrow e^+e^-\gamma$, B.R. = 1.2%. Earlier study: Few events through baffle.

Let GEANT4 do the decays. To get rates we don't need target, baffle, or detector materials, just virtual flux detector. Detector is size, shape, and position of front face of first baffle plate.

Used 4.4e7 π^0 events (generated by Ye Tien), compare to 1e6 DIS e^- events.

Require $E > 2$ GeV, $15° < \theta < 45°$

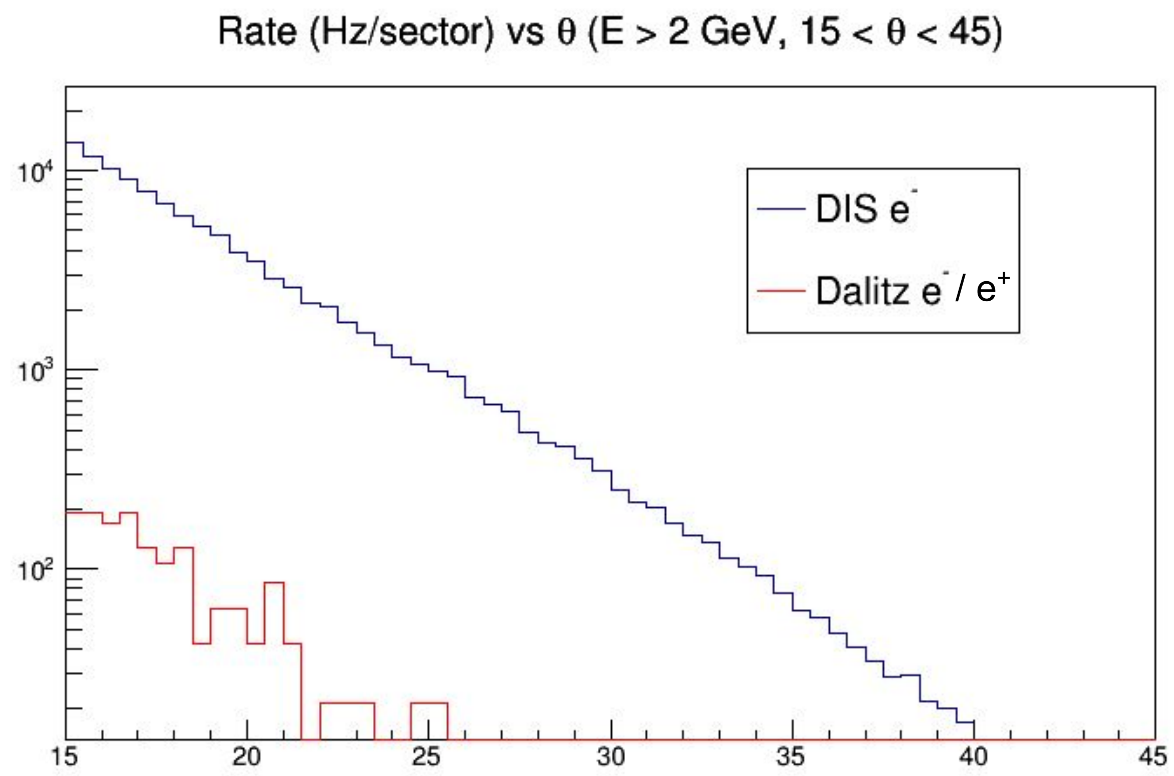
Angular distribution

DIS rate 107 kHz/sector

Dalitz rate 1.6 kHz/sector

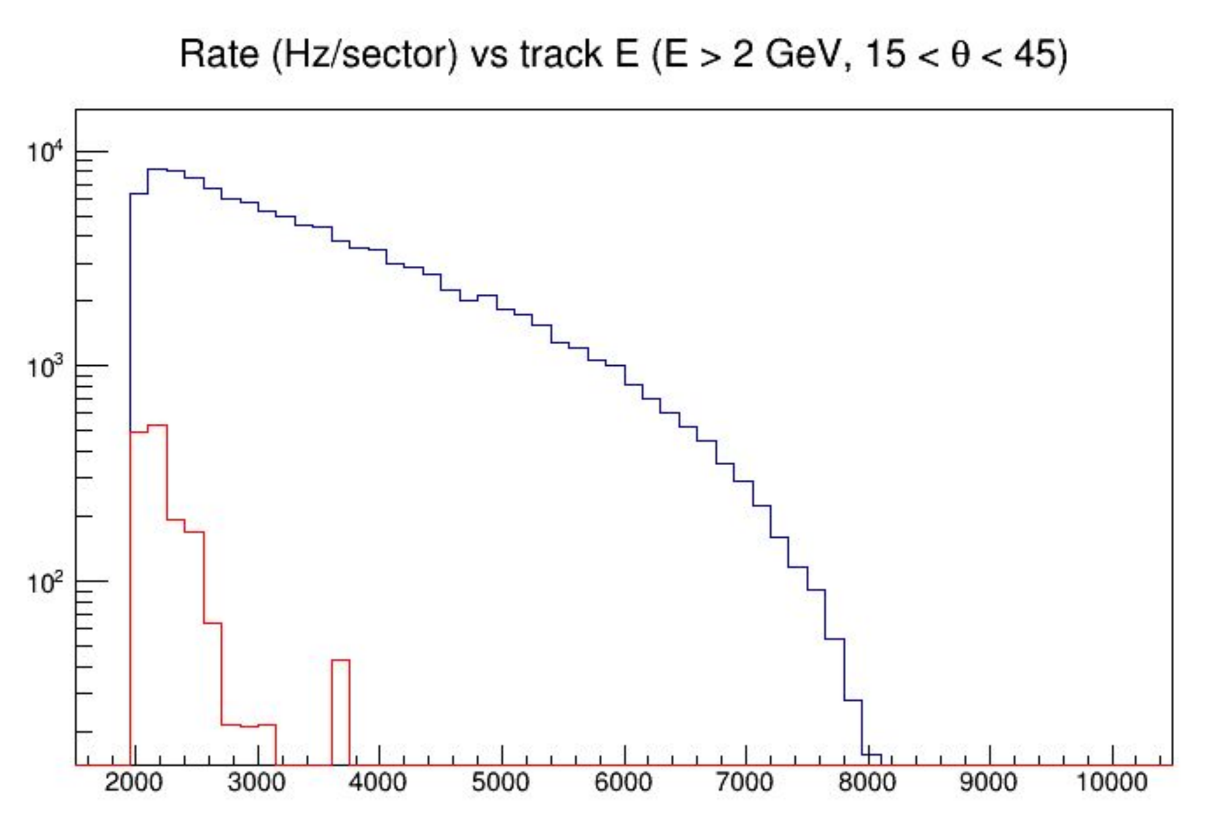
(Mostly below 22° where we have little acceptance)

Half of Dalitz is e^+, mostly should not get through baffles

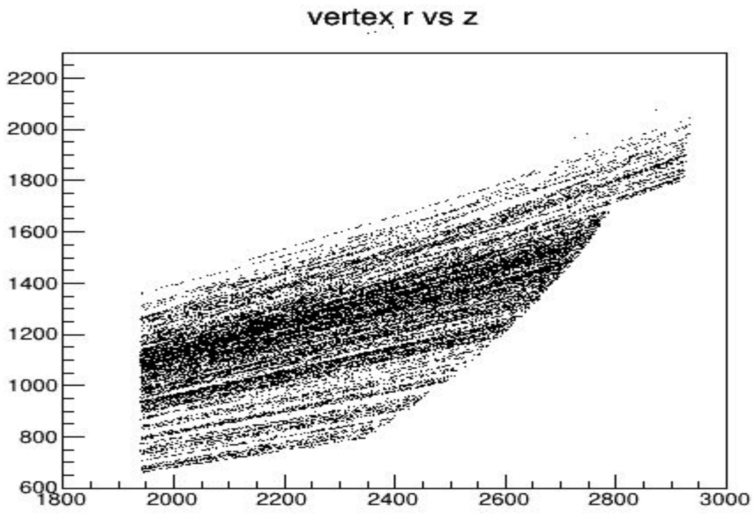


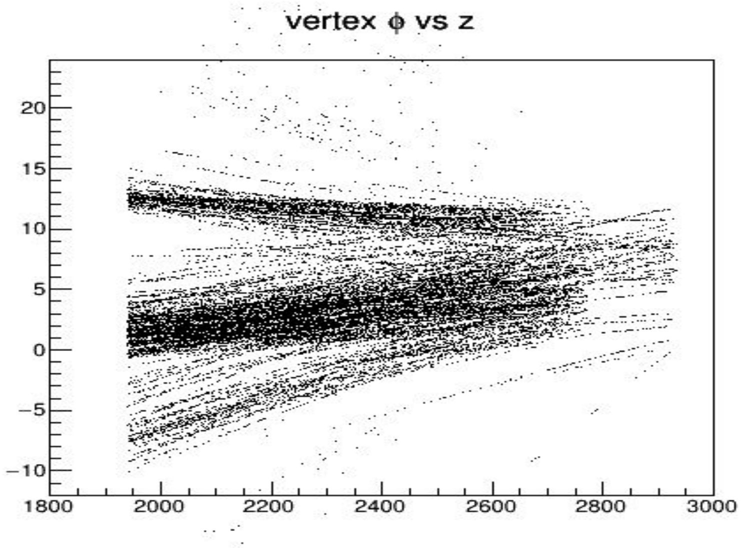
Energy spectrum

Dalitz mostly < 2.5 GeV



Optical photon vertex positions for Cerenkov photons entering Winston cone aperture, but with cone removed
Hall D π0

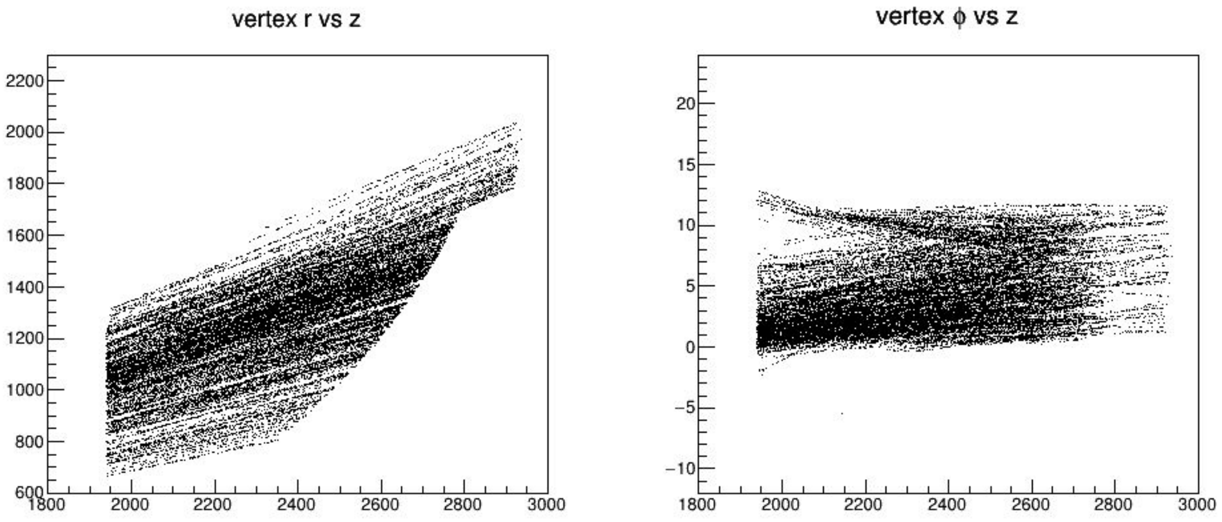




Looking only at sectors where an LGC trigger occurs

π0 LGC trigger rate down ~45%
DIS LGC trigger rate down ~10%

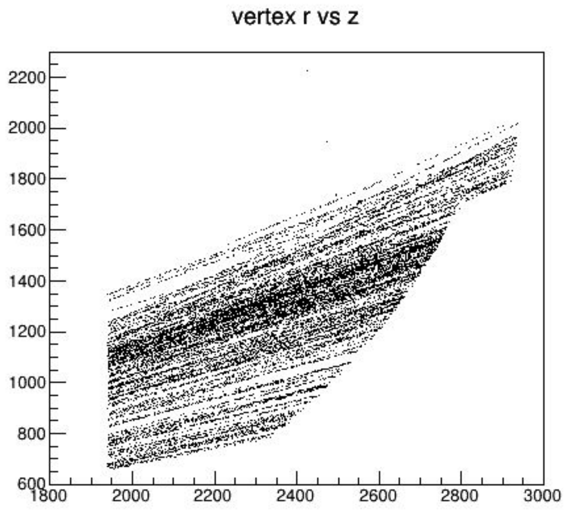
Optical photon vertex positions for Cerenkov photons entering Winston cone, with blinders
Hall D π0

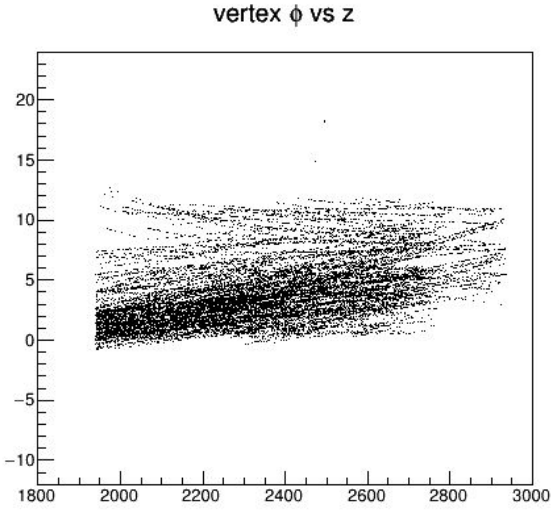


Looking only at sectors where an LGC trigger occurs

π0 LGC trigger rate down ~45%

Optical photon vertex positions for Cerenkov photons entering Winston cone aperture, but with cone removed, with blinders
Hall D π0





Looking only at sectors where an LGC trigger occurs

π0 LGC trigger rate down ~70%

Simulations

- PMT windows (glass 1.5 mm thick) is made sensitive
- 10^6 events each Hall D π^-, π^+, π^0
- 10^8 events each beam on target full physics and EM only
- Glass: Count instances of >= 2 PE in PMT for events with no electron “hits” in glass (these mostly are from high energy photons hitting glass and depositing energy)
- Gas: Count instances of >= 2 PE in PMT for events with no electron “hits” in glass (these are from optical photons entering glass)

Rates

- Singles rate R (in kHz/PMT) obtained from counts
- Random coincidence rate (2 primary events piling up; in kHz/sector) is $(9{\times}8)R^2\tau$ where τ=30 ns
- Correlated coincidence rate (2 PMT signals in same event; in kHz/sector) obtained from counts
  - In gas: multiple tracks radiating, but rare
  - In glass: multiple tracks hitting, electrons crossing over between PMTs, or optical photons crossing over are all seen but rare and create few PMT signals

Pions

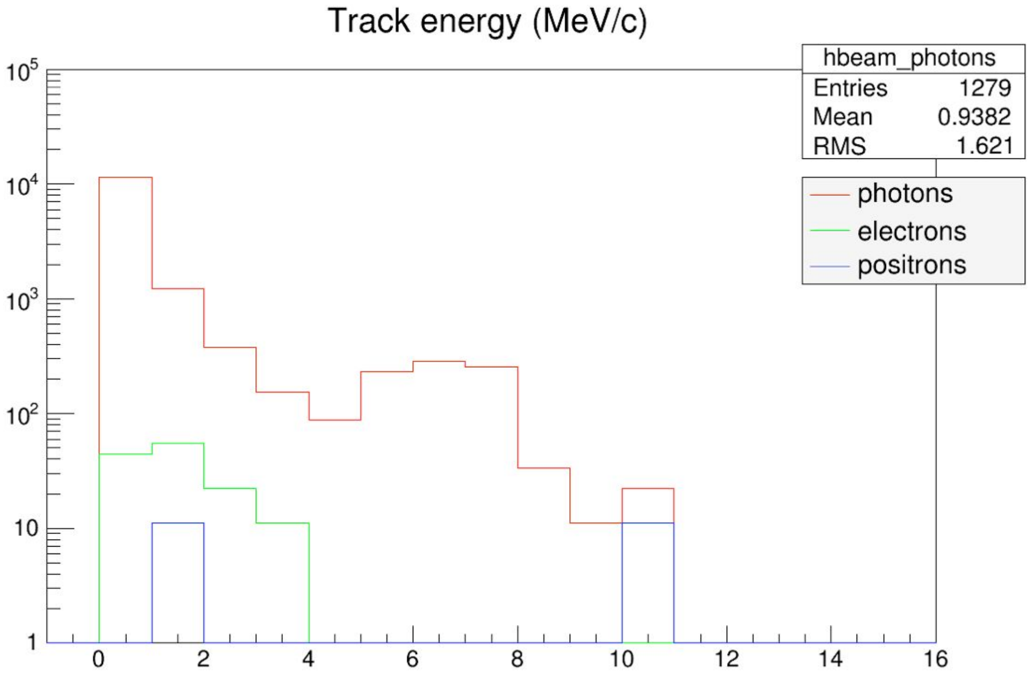
	Singles		Random coincidence rate	Correlated coincidences	
	# PMTs per 3*10^6 pions	Rate (kHz/PMT)	(kHz/sector)	# Sectors per 3*10^6 pions	Rate (kHz/sector)
Sum π					
~~PMTs with glass hits~~	~~1262~~	~~133~~	~~88~~	~~50~~	~~47~~
PMTs with glass hit signals	196	20	1	9	[illegible]
PMTs with gas hit signals	1863	190	78	996	915

Beam on target

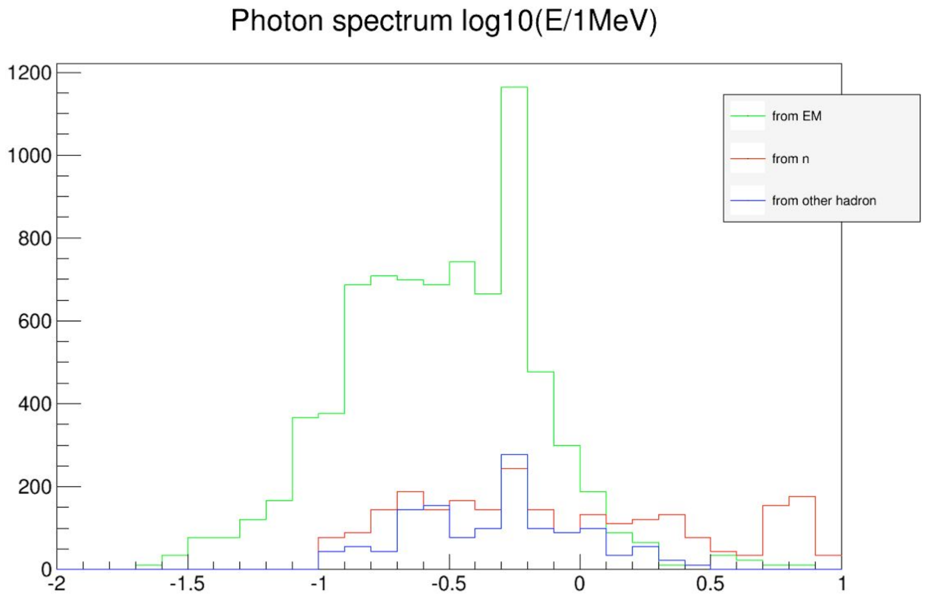
	Singles		Random coincidence rate	Correlated coincidences	
	# PMTs per 10^8 primaries	Rate (kHz/PMT)	(kHz/sector)	# Sectors per 10^8 primaries	Rate (kHz/sector)
Beam on target					
~~PMTs with glass hits~~	~~23~~	~~266~~	~~158~~	~~1~~	~~104~~
PMTs with glass hit signals	4	46	5	0	0
PMTs with gas hit signals	25	289	180	14	1456
~~**Beam on target EM only**~~					
PMTs with glass hits	15	173	65	0	0
PMTs with glass hit signals	1	12	0	0	0
PMTs with gas hit signals	1	12	0	0	0

Gas rate ~ 1 MHz/sector

Glass rate ~ 10 kHz/sector



Spectra of photons, electrons, positrons in PMT glass (“beam” data). Linear scale.



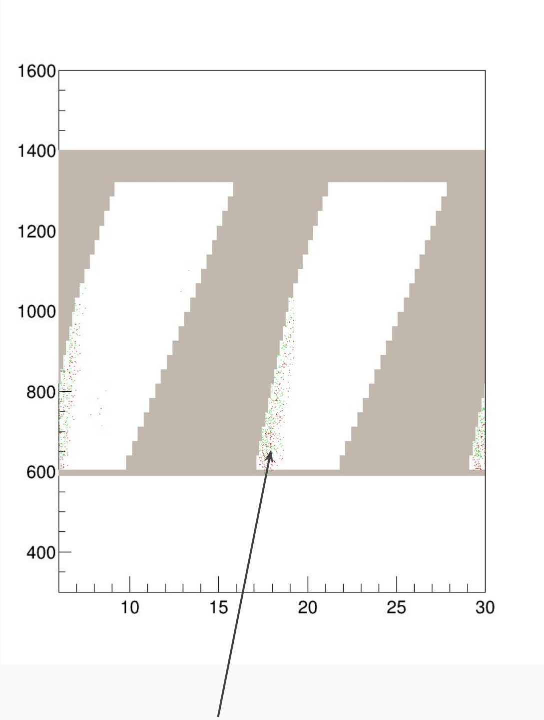
Spectrum (logarithmic *x* axis, 0 is 1 MeV etc.) of photons hitting PMT glass (“beam” data). Photons from EM processes dominate below ~1.5 MeV. Photons from neutrons dominate above that.

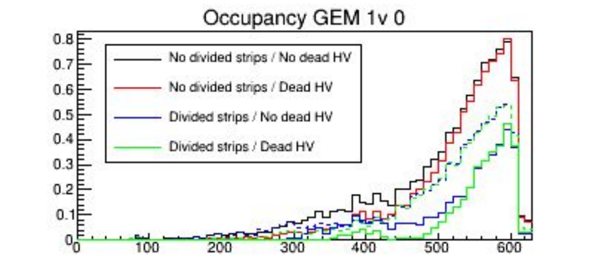
Line of sight acceptance

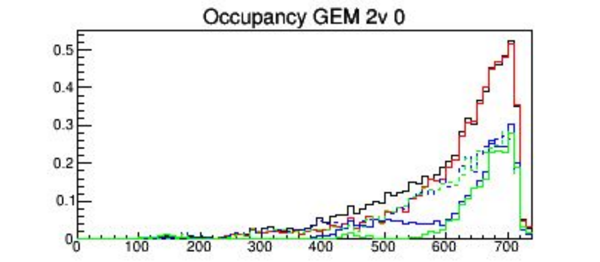
The CLEO2 baffle design has some acceptance for photons coming from the z axis in the target.

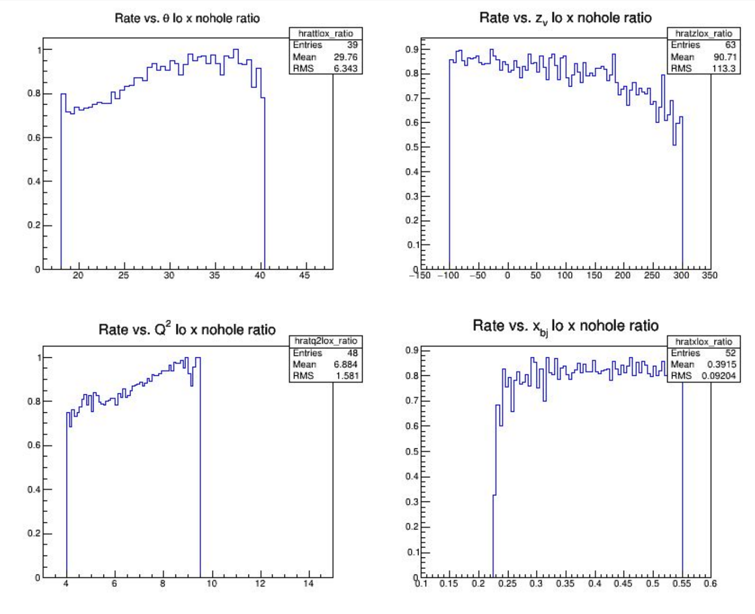
We observe hot spots with large background rates affecting e.g. GEM occupancy.

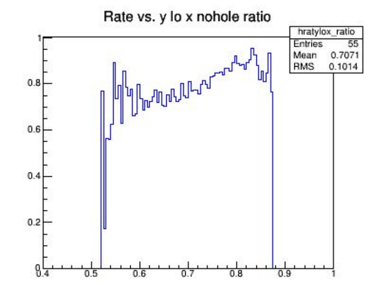
How would reducing or closing these “holes” change signal and background?



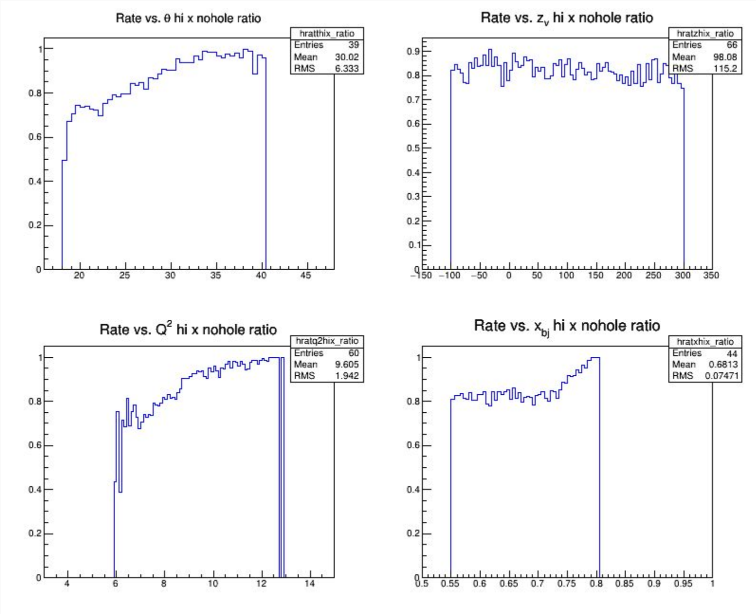


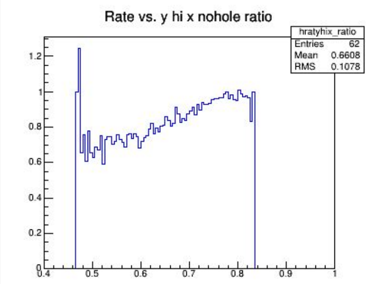






DIS rate ratios,
x<0.55,
Q^2>4 GeV^2,
W>2 GeV





DIS rate ratios,
x>0.55,
Q^2>4 GeV^2,
W>2 GeV

With no hole baffles, DIS rate after last baffle plate is reduced by 0 to ~30% compared to CLEO2 baffles, depending on vertex and kinematics. Reduction is ~20% for x < 0.7.

Photon acceptance

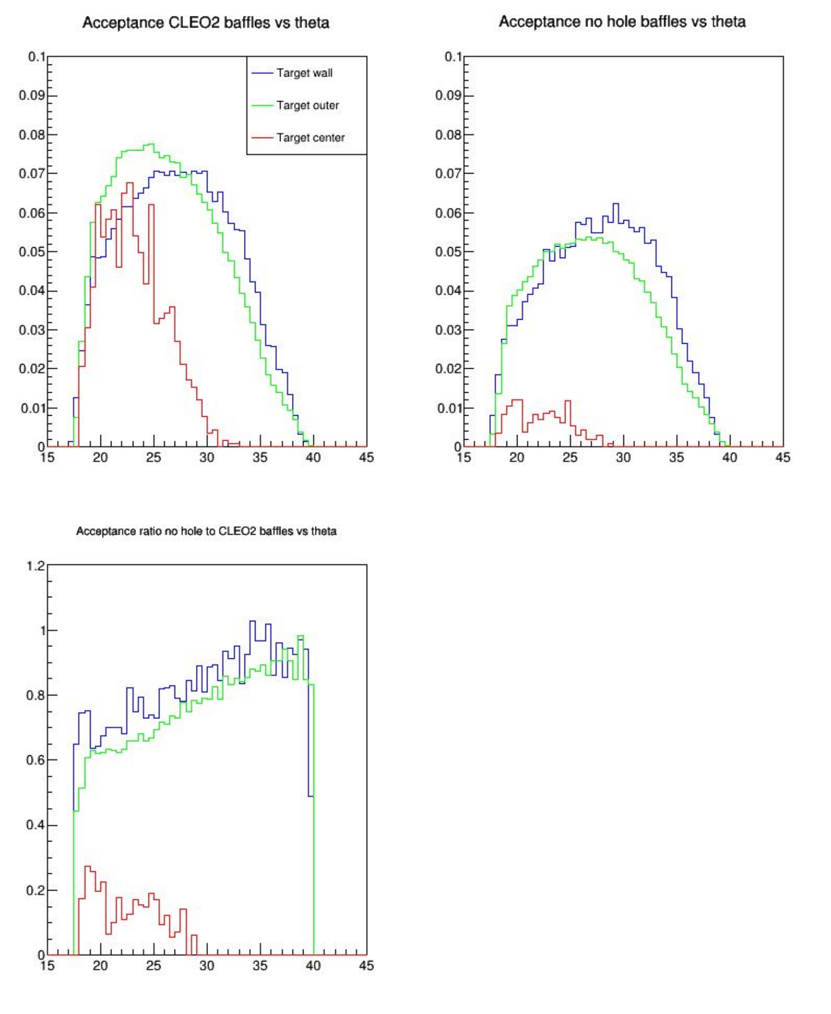
“No hole” only for vertices on axis in the target!

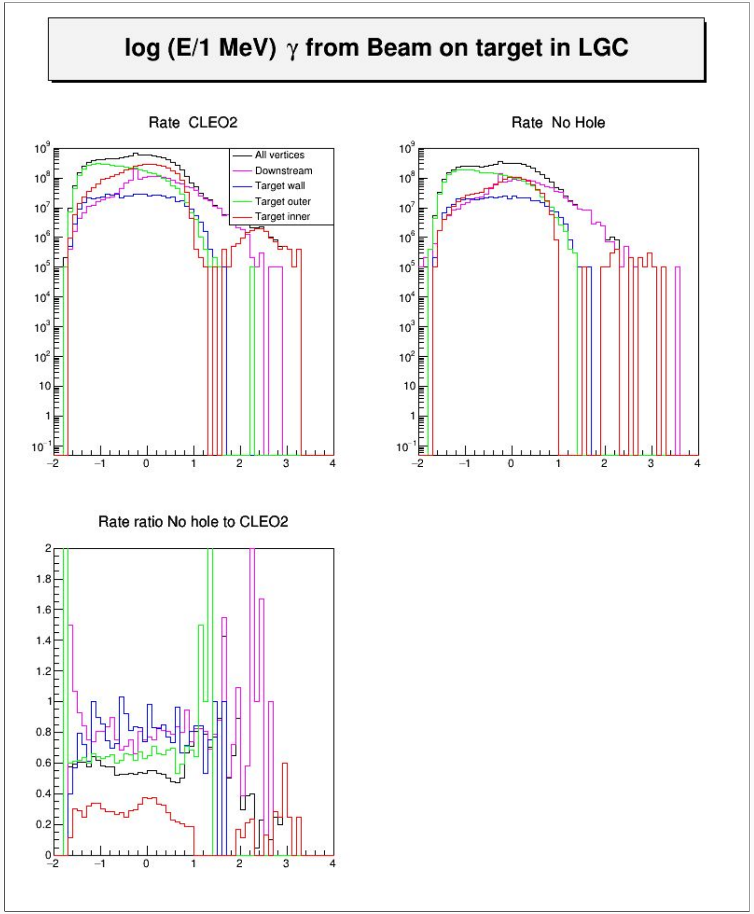
Geometric acceptance (after last baffle plate) for photons is still nonzero off axis.

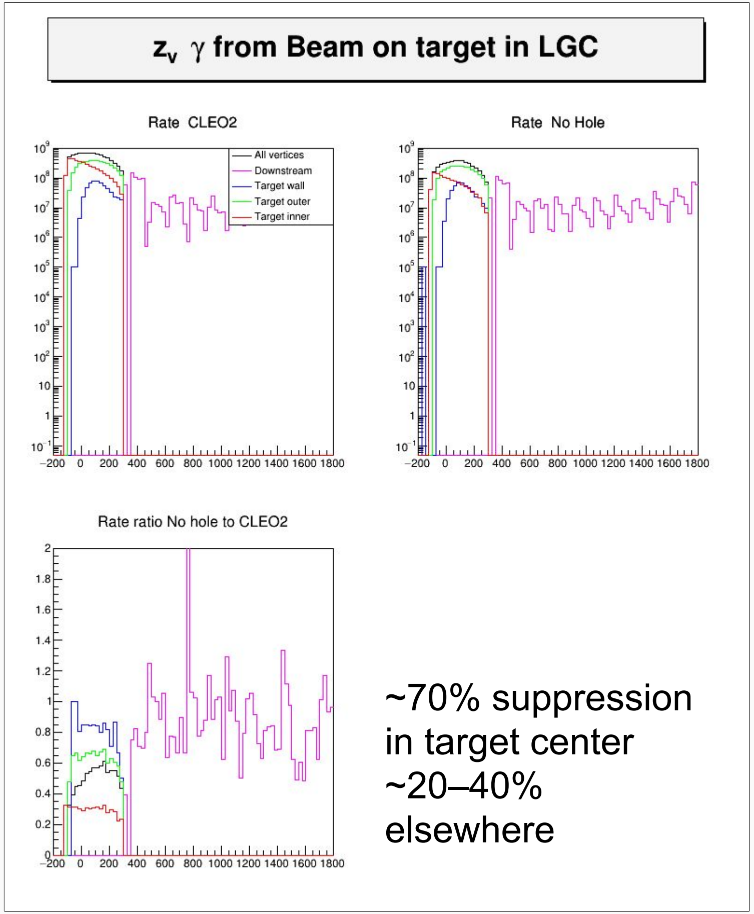
Target center: r < 2.5 mm

Target outer: 2.5 < r < 25 mm

Target wall: r >= 25 mm

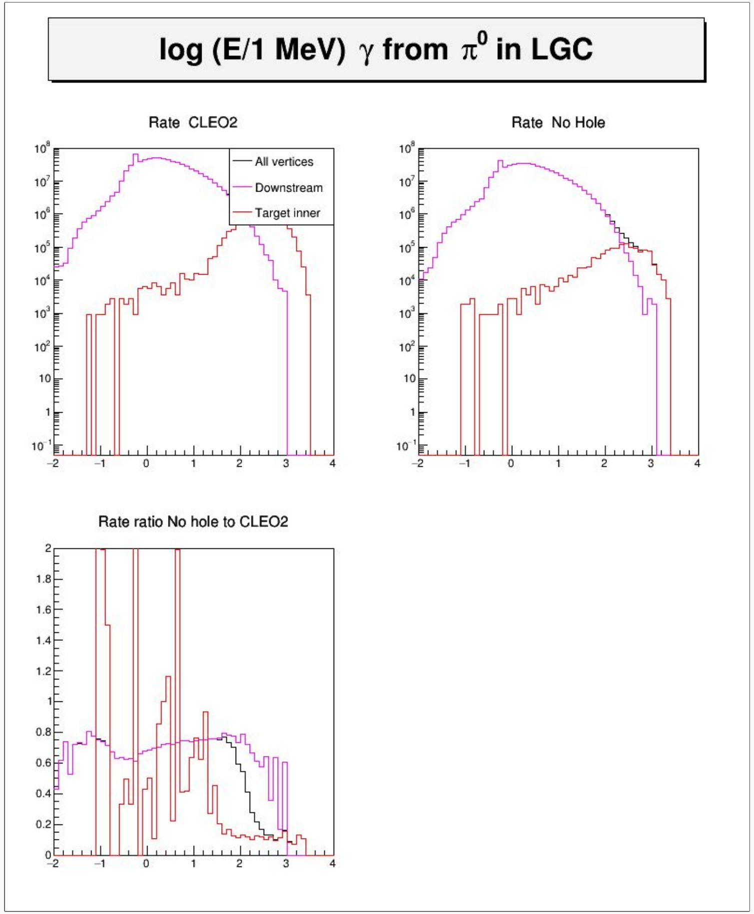


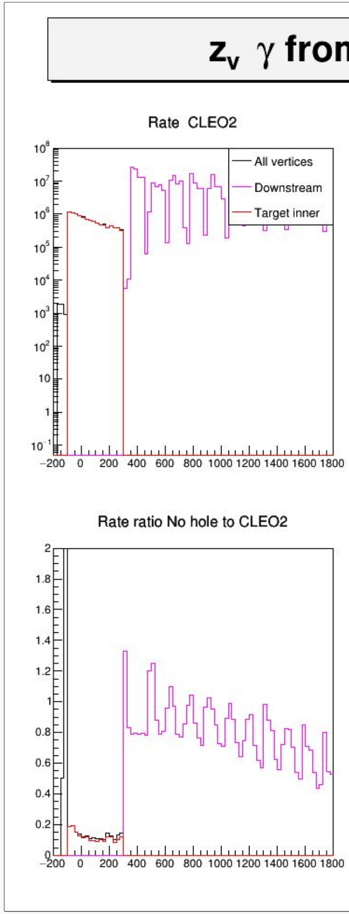




~70% suppression in target center
~20–40% elsewhere

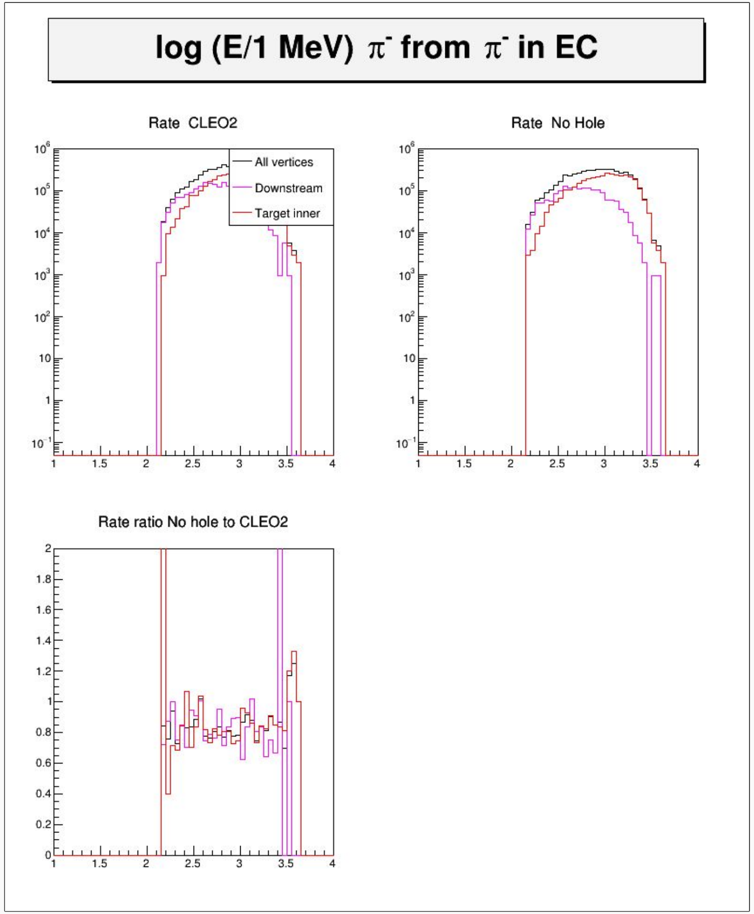
Rates for photons at LGC window from beam on target

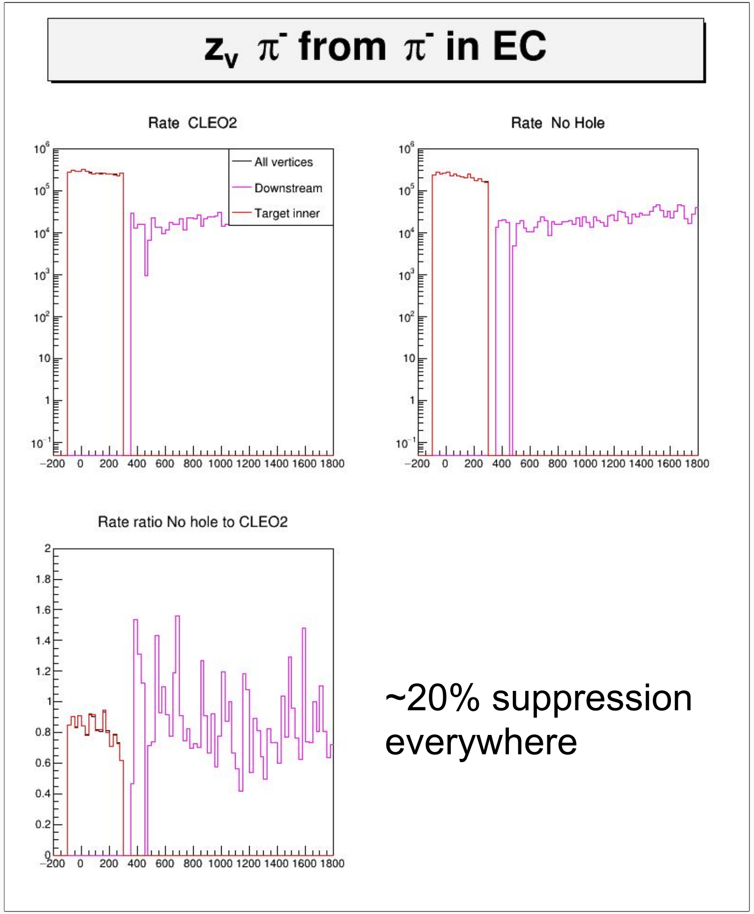




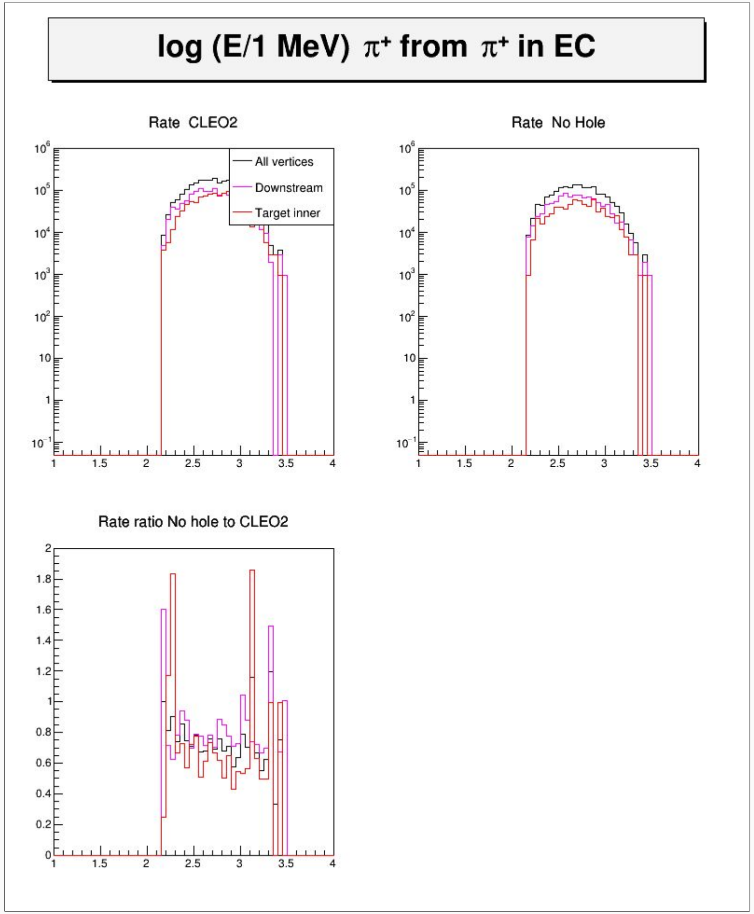
~85% suppression
in target center
~30% elsewhere

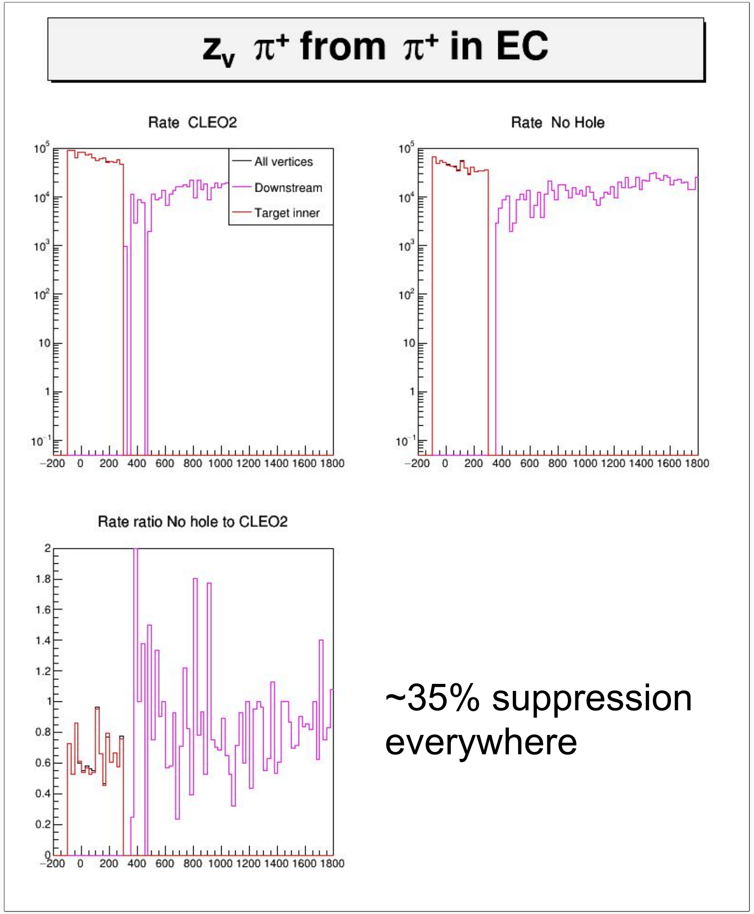
Rates for photons at LGC window from π0





~20% suppression everywhere





~35% suppression everywhere