RGH Background Rates

RGH Experiment Workshop Nov 13-14, 2026

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Outline

1 **Motivation**

Physics and Background simulations

2 **Simulation Setup**

Used GEMC geometry, fields, and the L = 5×10^{33} $cm^{-2}s^{-1}$ design-luminosity choice

3 **ELMO Shielding Studies and DC, HTCC Background Rates**

ELMO configurations and their impact on DC sector / region occupancy

4 **FTOF Background rates and PMT Current Studies**

PMT anode-current estimates from species/origin breakdown of FTOF hit

5 **Torus Shielding**

FTOF PMT anode-current comparisons, original vs. new torus shield

6 **ECAL Background rates and Trigger-Level Impact**

CLAS12 trigger thresholds, sector 1 vs. sector 4, and next steps

7 **Summary and Outlook**

1. The Physics Case for RGH

Four CLAS12 experiments, with transversely polarized target - originally **approved with rating A** by PAC39, and selected among the **high-impact JLab measurements** by PAC41, **highlighted in the 2023 NSAC** Long Range Plan.

RGH approved with NH_3 target by PAC 53 - 2025

Experiment	Contact	Title	Rating	PAC days
C12-11-111	M. Contalbrigo	Transverse spin effect in SIDIS at 11 GeV with a transversely polarized target using CLAS12	A	100 + 25
C12-12-009	H. Avakian	Measurement of transversity with di-hadron production in SIDIS with a transversely polarized target	A	100 + 25
C12-12-010	L. Elauadrhiri	Deeply Virtual Compton scattering at 11 GeV with transversely polarized target using the CLAS12 detector	A	100 + 25
C12-11-111A	H. Avakian	Measurements of Single Spin Asymmetries in exclusive production of hadrons with RGH transversely polarized target		100 + 25

Slide from M. Contalbrigo

Together: **precision parton-distribution measurements in the unexplored high-x valence region - complementary to one of the pillars of the EIC physics program.**

125 PAC days runs

25 commissioning + calibration, 100 production

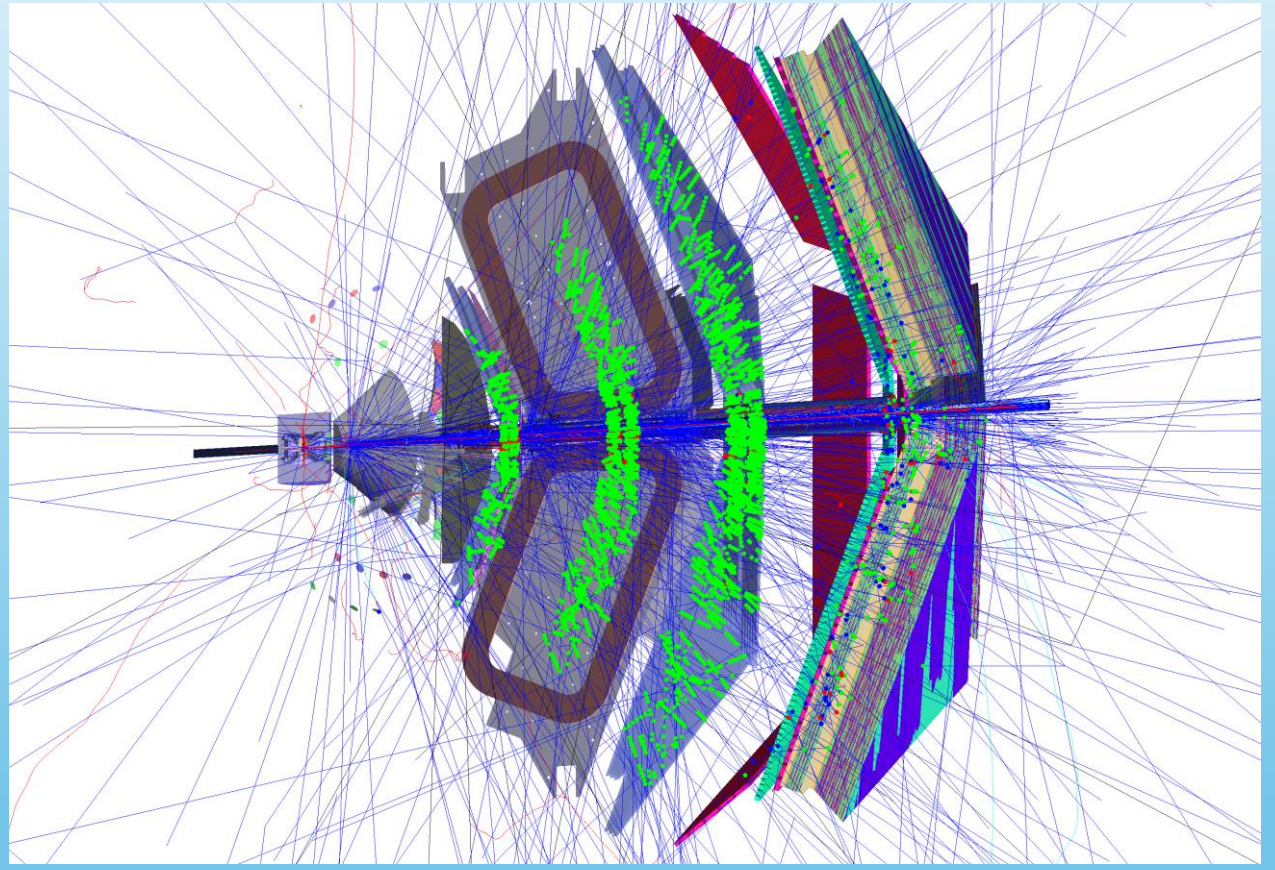
Tomorrow afternoon session:
Lorenzo Polizzi (INFN), Harut Avagyan (JLab), Anselm Vossen (Duke University/JLab)

1. Simulating RGH Backgrounds

- Background studies set the achievable RGH luminosity.
- GEMC guides shielding design to keep background manageable at design luminosity.

The Background Sources

- There are three main components in the background:
- 1. Beam particles that lose energy in the target material and bend outside the beam orbit into the detector acceptance (the "sheet of flame").
- 2. Shower particles generated directly in the target region.
- 3. Secondary interactions in material downstream of the target, especially in the shielding surrounding the CLAS12 beampipe.



GEMC View of a Lumi Event in RGH FD System

Goal:

- Simulate the beamline and FD in GEANT4, characterize the background, then shield it down to design luminosity.

2. Simulation Setup

rgh_marco_new_kr.gcard · GEMC 5.10 (ifarm)
clas12_background (analysis code)
RGH Background Study (clas12 note)

Geometry & Fields

Target - Transverse NH_3 + cryostat, 5 T transverse magnet

Beamline - Custom ELMO cone (downstreamCone_mix)

Detectors - Full CLAS12 Forward Detector: DC, HTCC, FTOF, ECAL; solenoid is geometry only, no field

Fields - Torus x −1 (e^- inbending) + transverse target field

Beam - 10.6 GeV e- at 2.15°,
start at (x, y, z) = (-3.38, 0, -90) cm

Design Luminosity

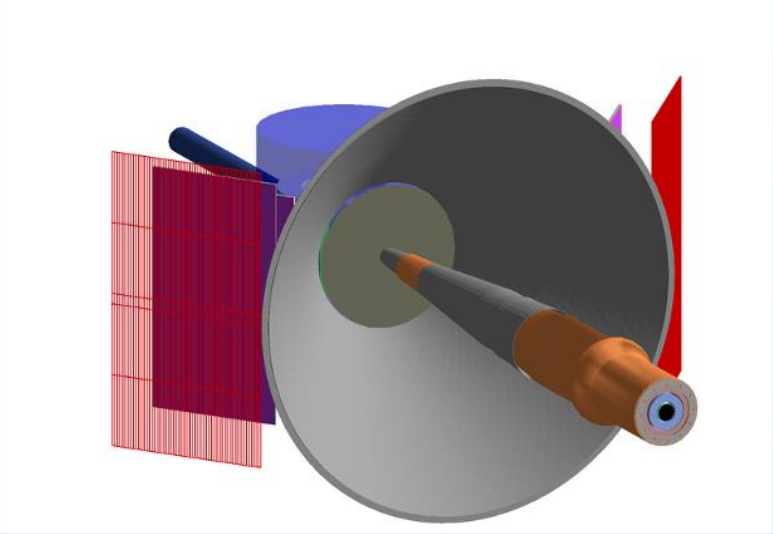
$$L = 5\times10^{33}\ cm^{-2}s^{-1}$$

LUMI_EVENT = 1350 → 1350 beam e^- per 252 ns window (4 ns spacing, CEBAF 249.5 MHz RF) = full design luminosity.

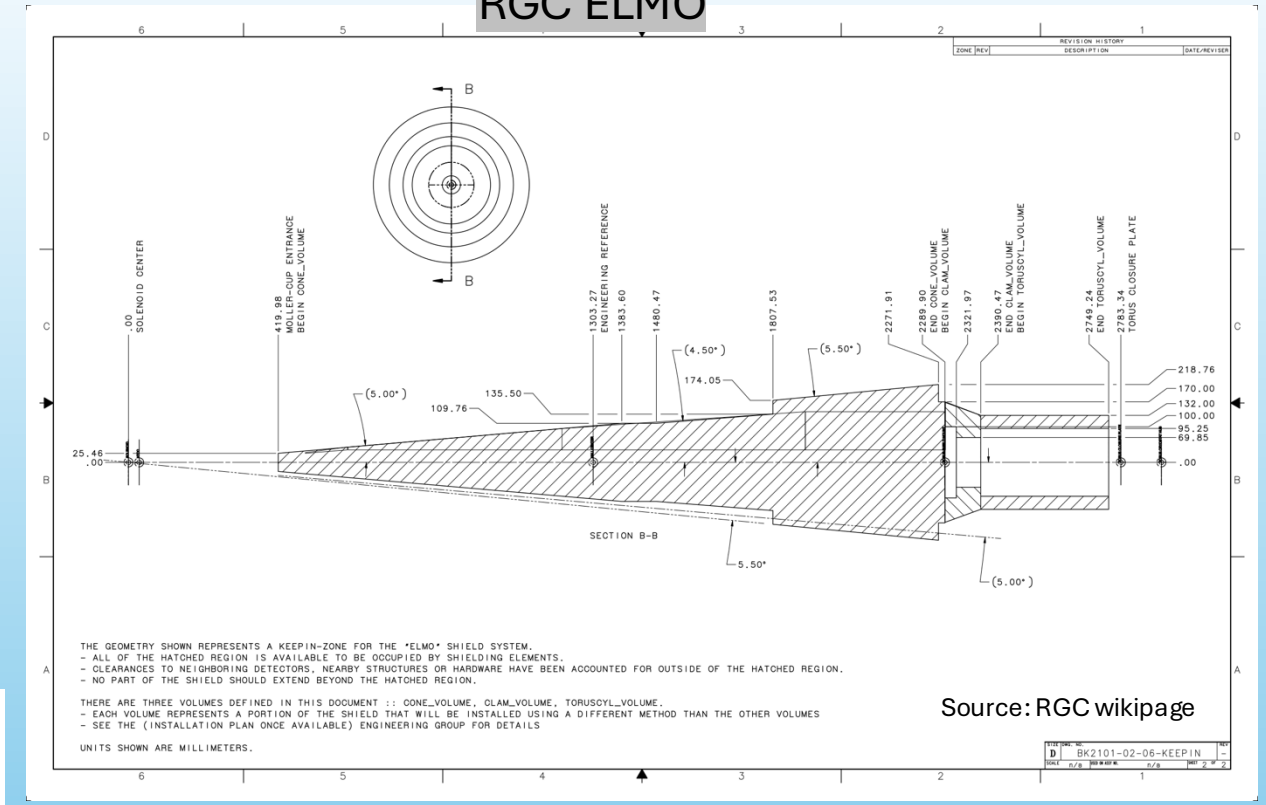
rate(L) = rate(N) × 1350 / N

Fewer bunches (N = 225/450/675) cut CPU time; -lumi N -time 252 rescales back to design luminosity.

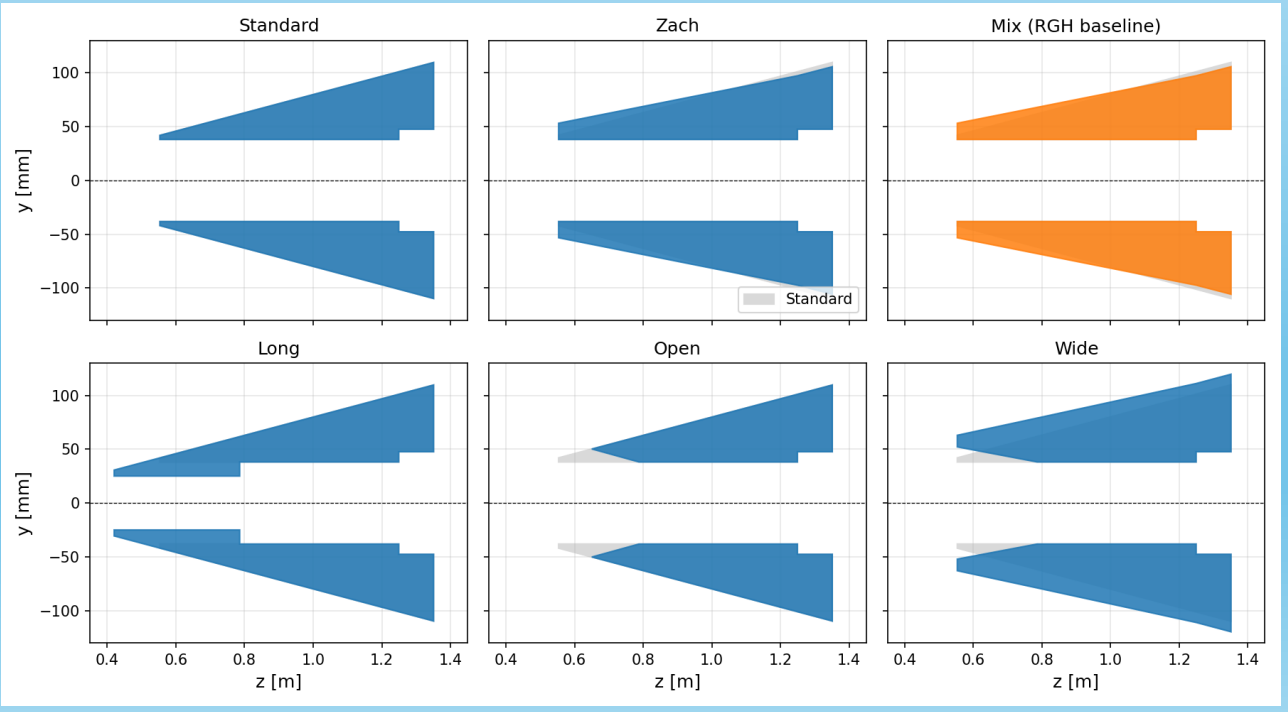
3. ELMO Shielding Studies



RGC ELMO



Source: RGC wikipage



Region-averaged DC wire occupancy (%, no sector 4) for various ELMO configurations.

DC region	Standard	Zach	Mix	Long	Open	Wide
1	6.8	3.3	2.7	7.9	6.0	2.0
2	2.2	1.6	1.6	2.6	2.0	1.4
3	5.0	4.1	4.1	5.7	4.8	3.7

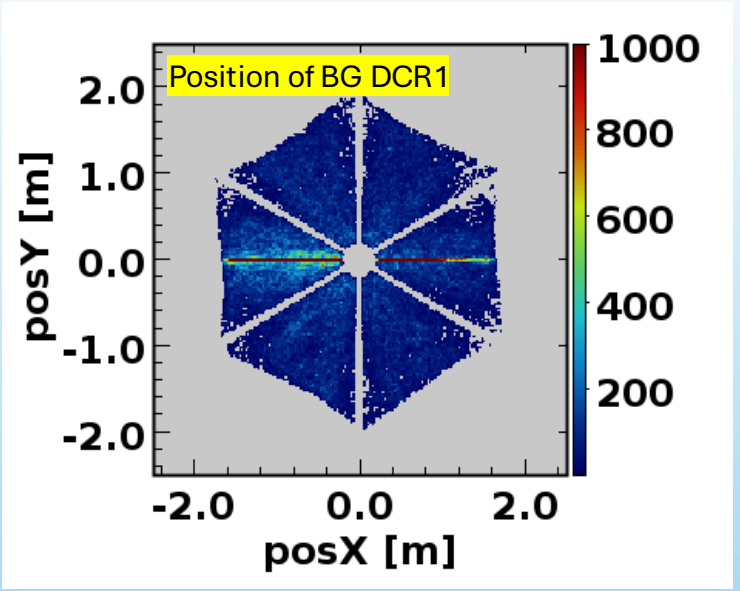
Although Wide variation performs better, due to its overlaps with HTCC Moller cone, Mix is used.

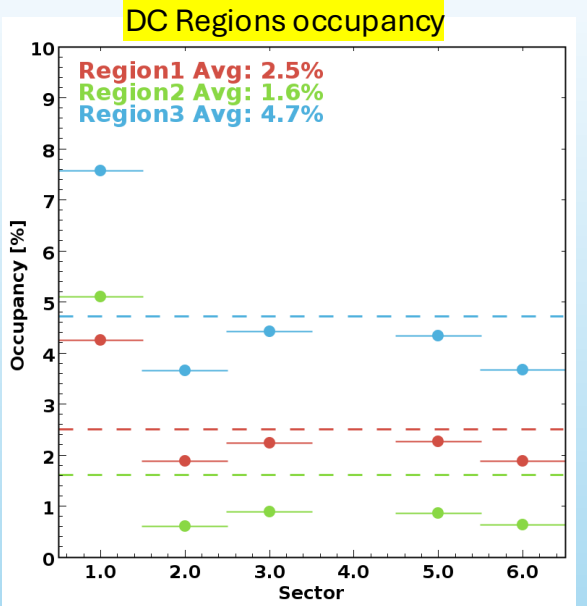
3. DC Background Rates

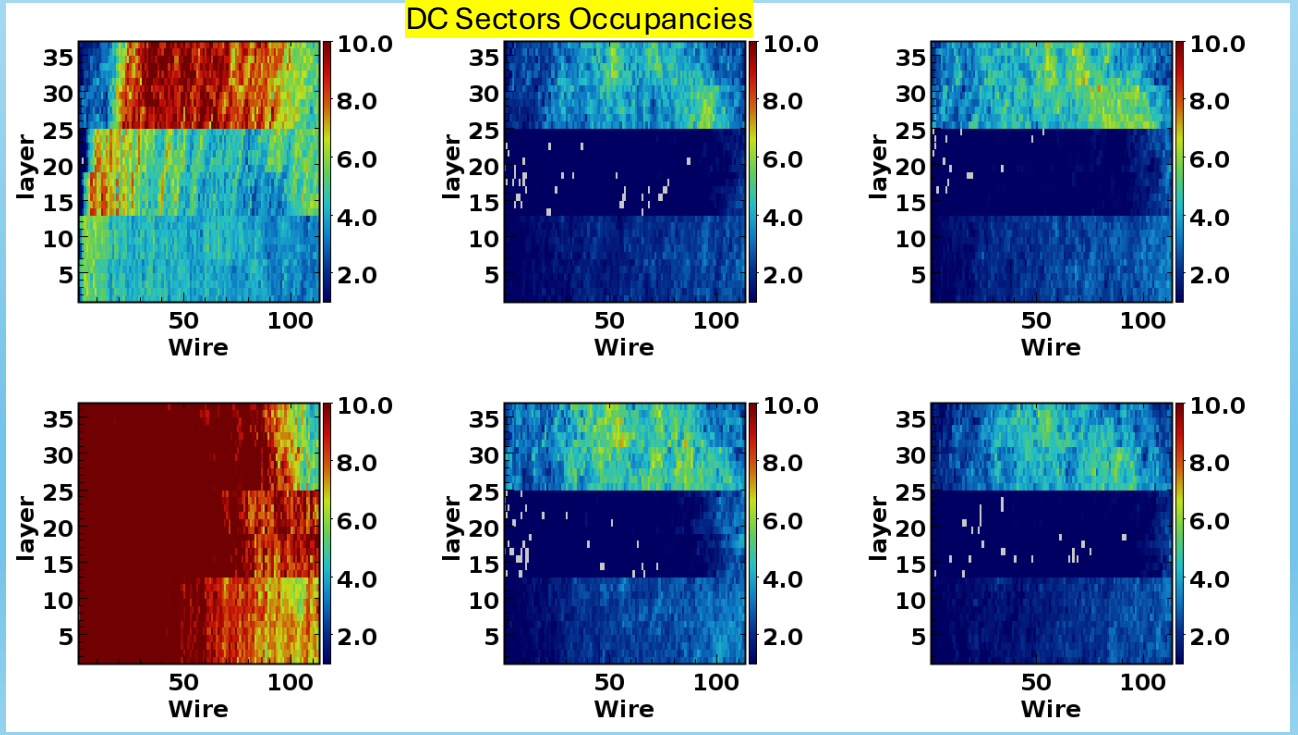
The DC readout keeps only one hit per wire per 0.5 – 1.5 μs gate, extra background hits corrupt the track. RGC tolerated 6-8% occupancy; RGH's design luminosity (5×10^{33}) assumes that same ceiling, sector 4's sheet-of-flame can blow past it.

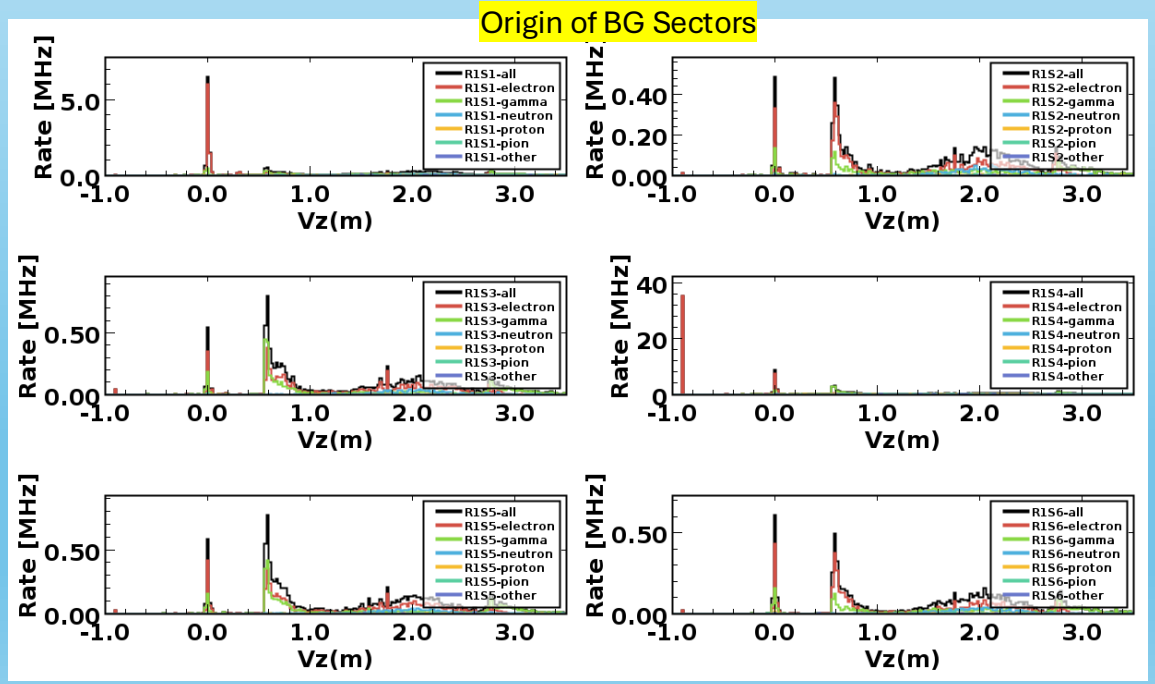
High-Lumi Upgrade will benefit, presentation by Rafayel Paremuzyan.

DC region time windows: 250 ns, 500 ns, 500 ns



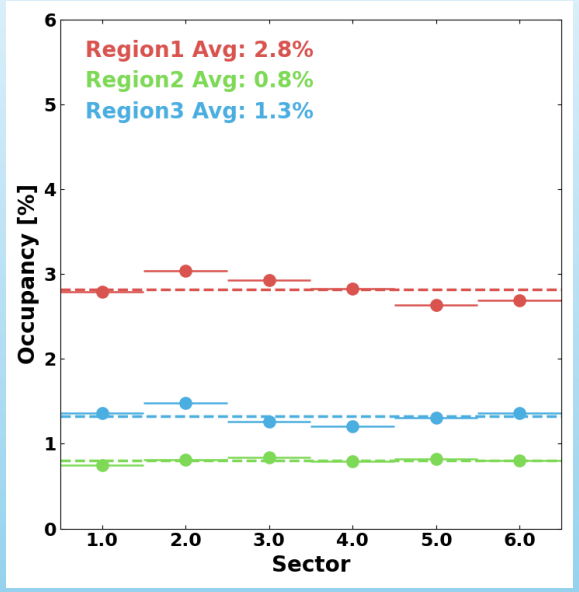






3. DC Background Rates Comparisons

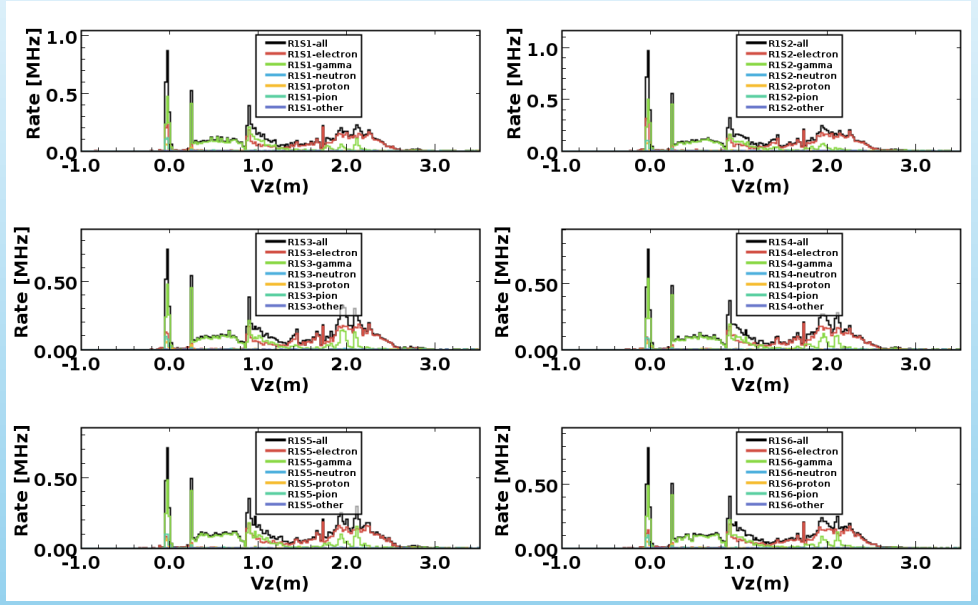
DC Regions Occupancies %

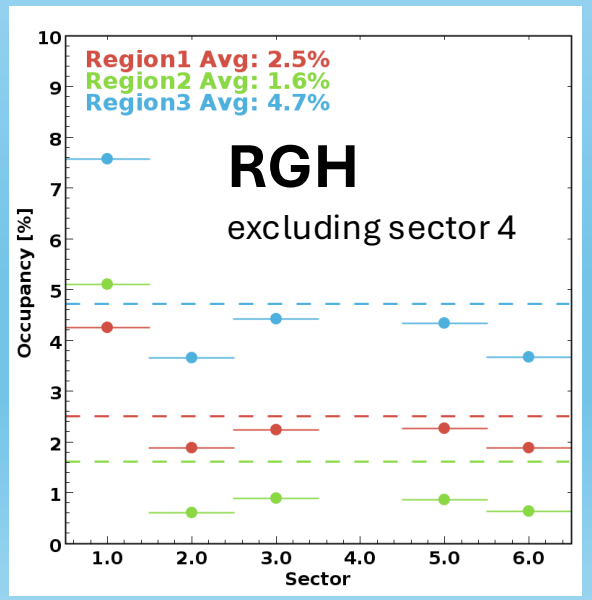


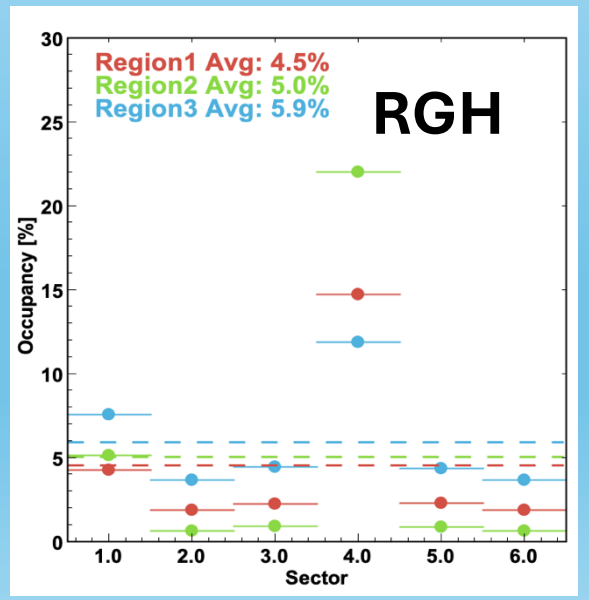
RGA

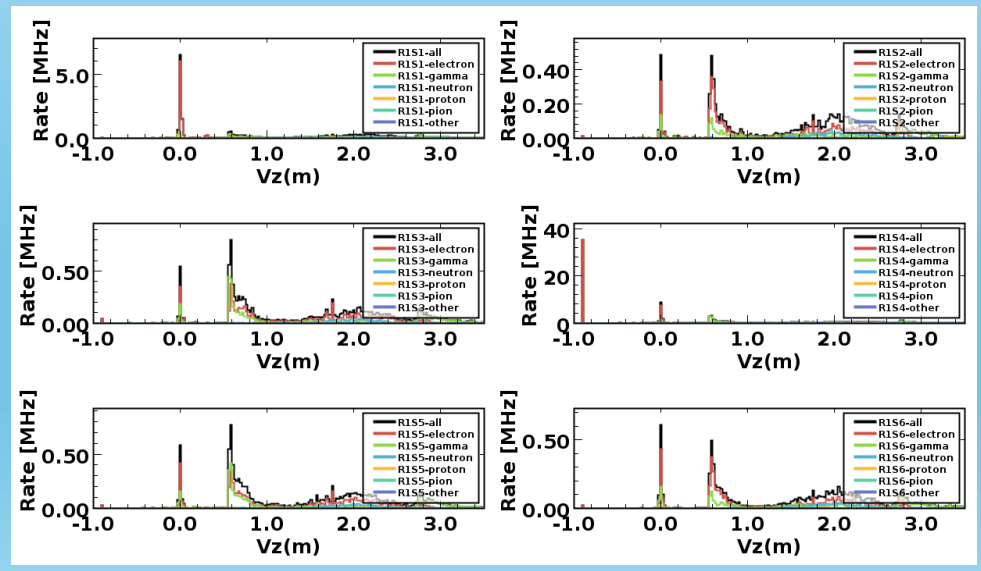
Fall 2018 sim

Origin of BG DC R1Sectors

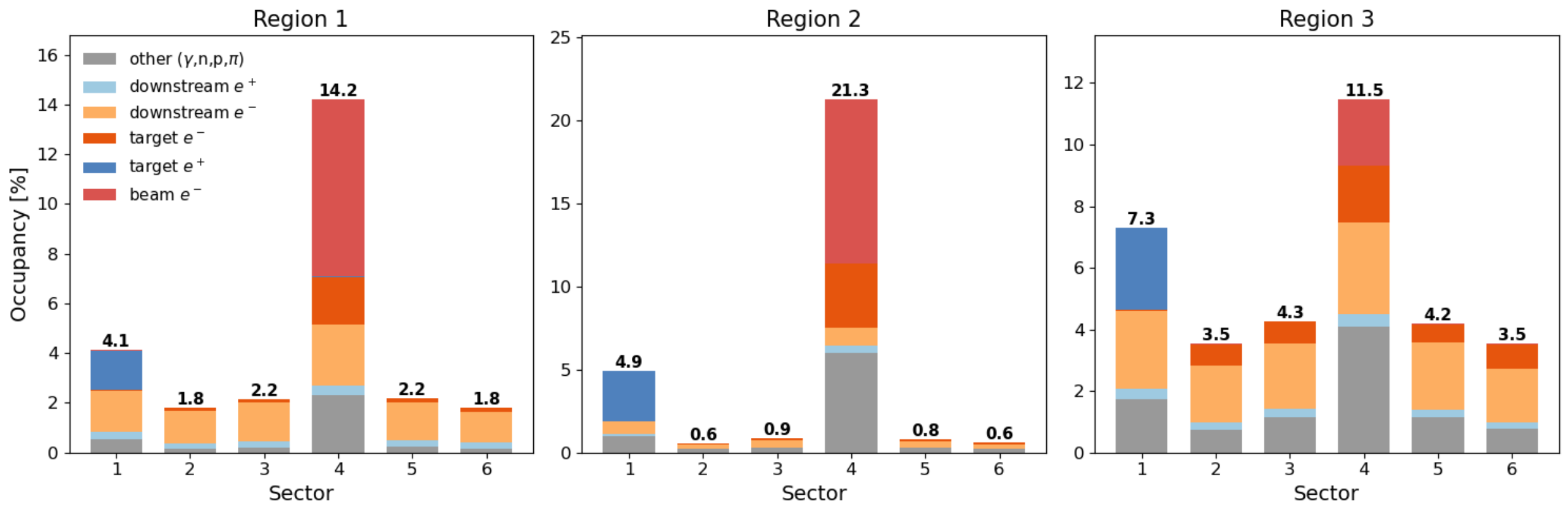








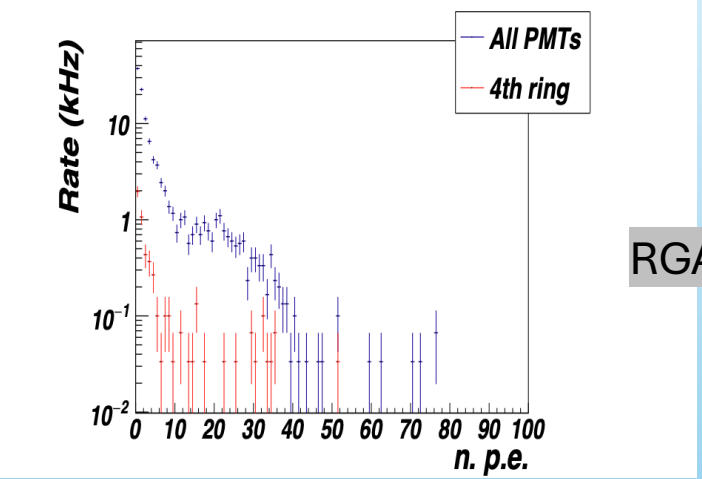
3. DC Background Rates Species/Origin Breakdown



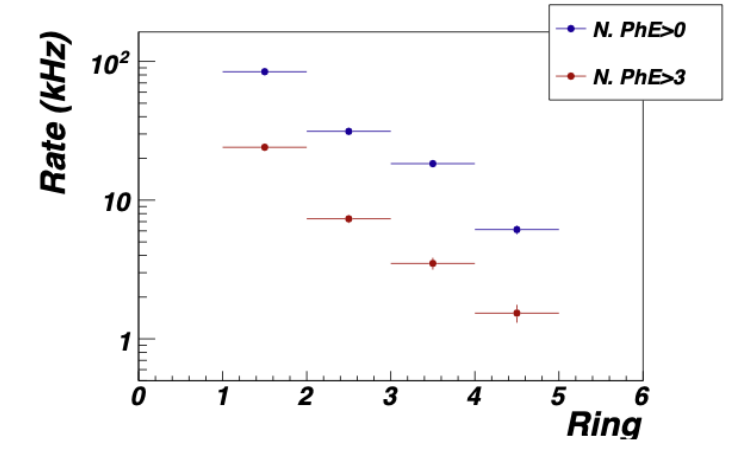
Sector 4 dominates all three DC regions - consistently topped by a large radiatively degraded beam e^- contribution, the sheet-of-flame signature. **Sector 1 is the only sector with a visible target-positron component** (pair production).

3. HTCC Background Rates Comparisons

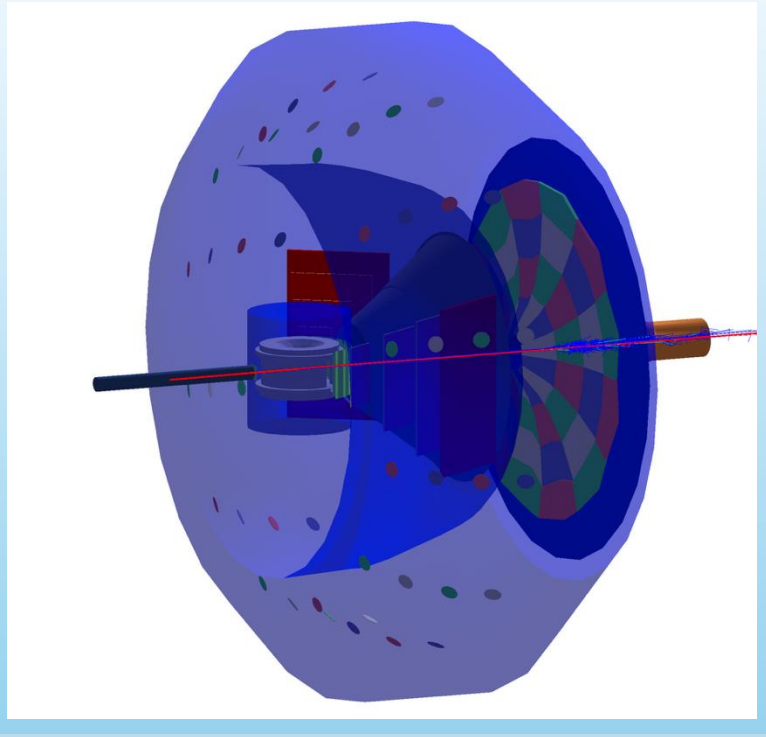
HTCC rates for CLAS12 Standard Config with Lumi: 10^{35} cm^{-2} s^{-1} :
number of photoelectrons (left) rates in the four HTCC rings (right)



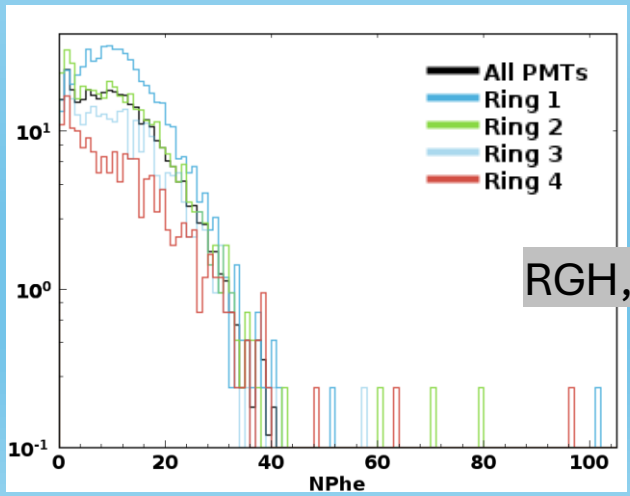
RGA



CLAS12 NOTE : Study of the electromagnetic background rates in CLAS12 R. De, D. S. Carman, C. Smith, S. Stepanyan, M. Ungaro

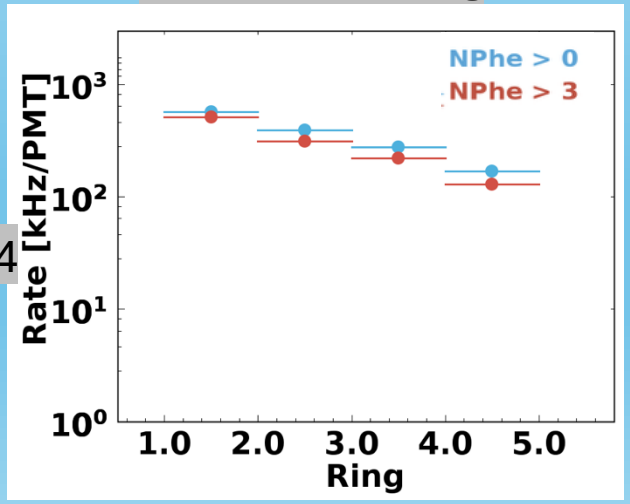


NPhe distribution per PMT



RGH, No S4

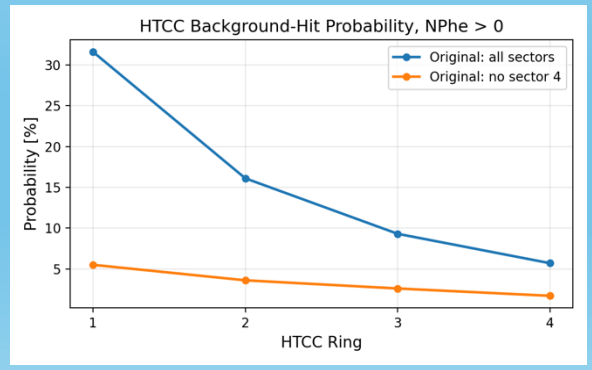
Rate Versus Ring



The probability of observing at least one random background hit in a detector time window Δt is

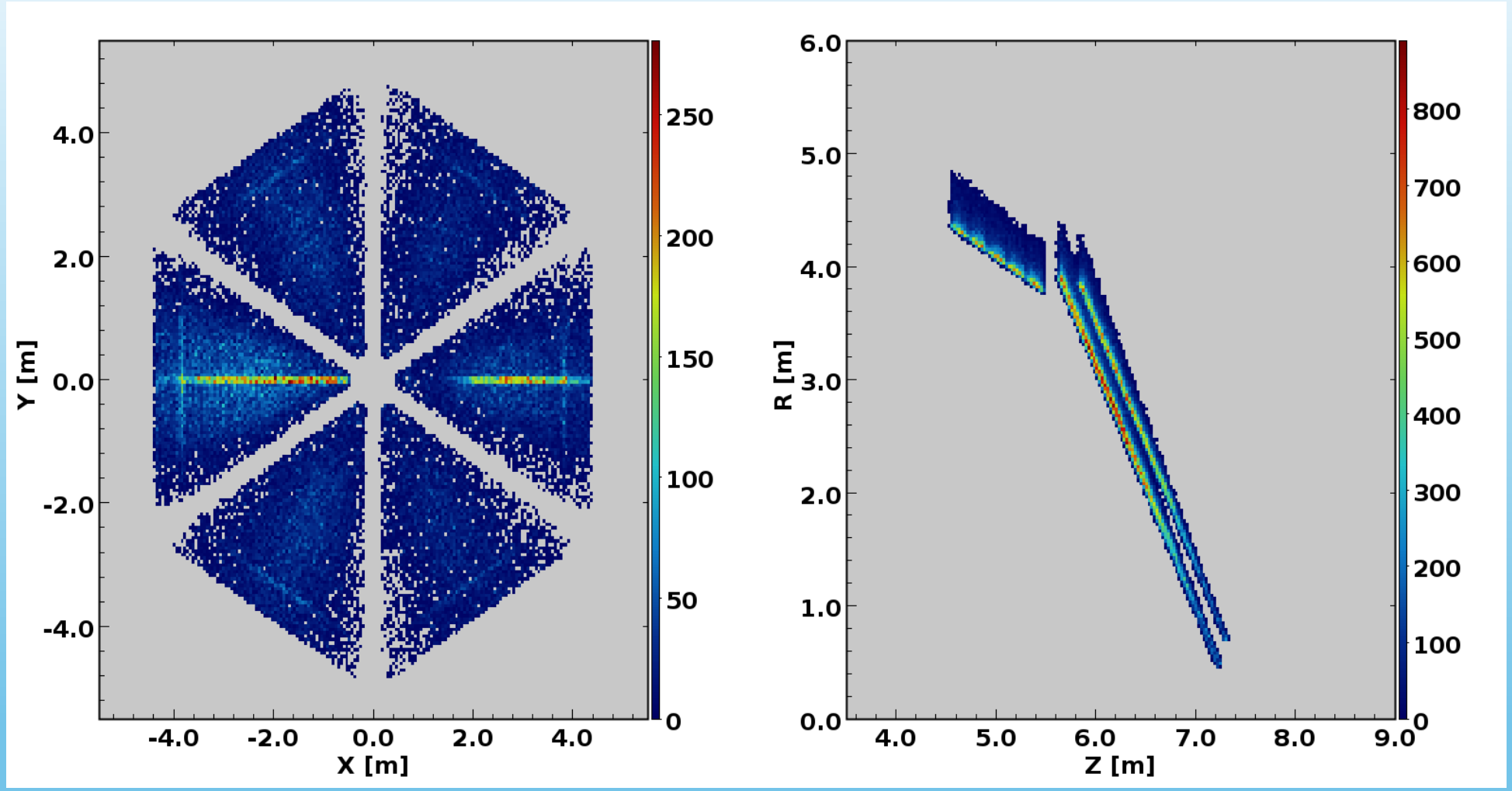
$$P(\geq 1) = 1 - e^{-R\Delta t},$$

where R is the background rate, Δt is time window.



R = 6×10^5 Hz
Δt = 100 ns = 1×10^-7 s
P(≥1) = 5.82%

4. FTOF Background Rates: Position of BG

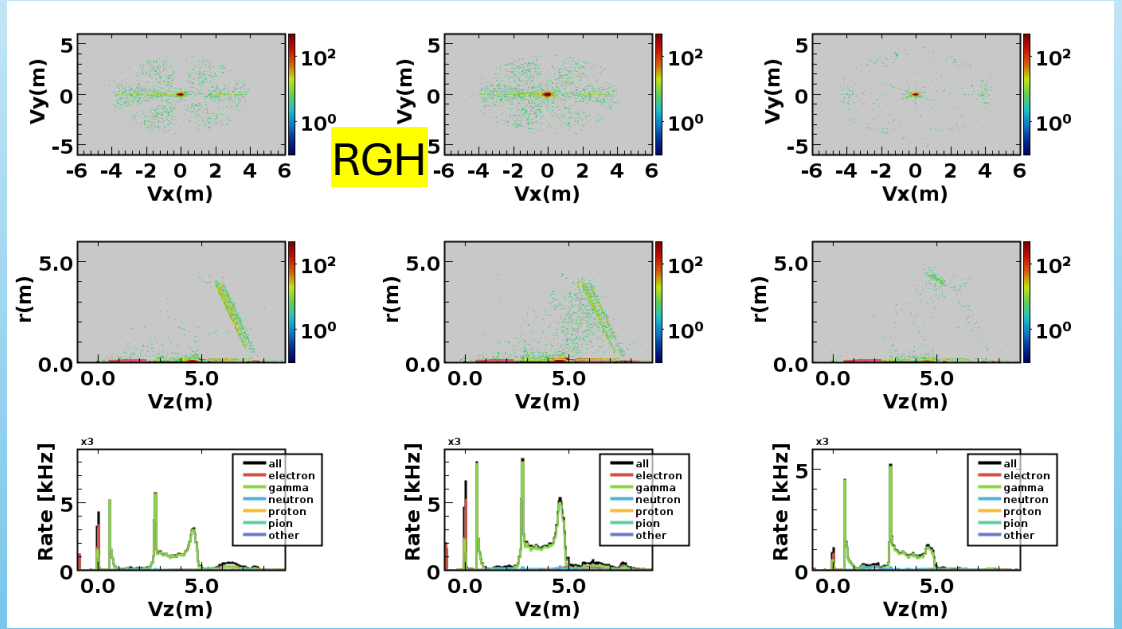


Same sheet-of-flame signature as DC; the horizontal band (X-Y, left) and the diagonal trajectory (R-Z, right) show the same radiatively degraded beam e^- / target e^+ sweep that hit DC now reaching FTOF.

4. FTOF Background Rates Comparisons: Origin of BG

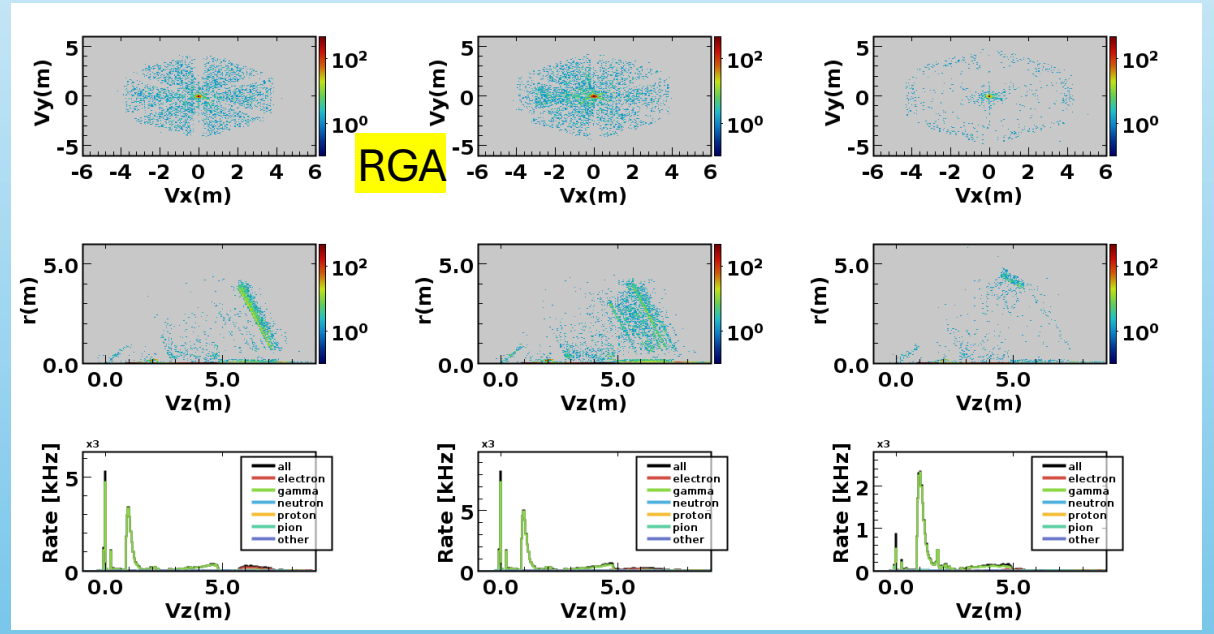
Panel 1A | Panel 1B | Panel 2

RGH



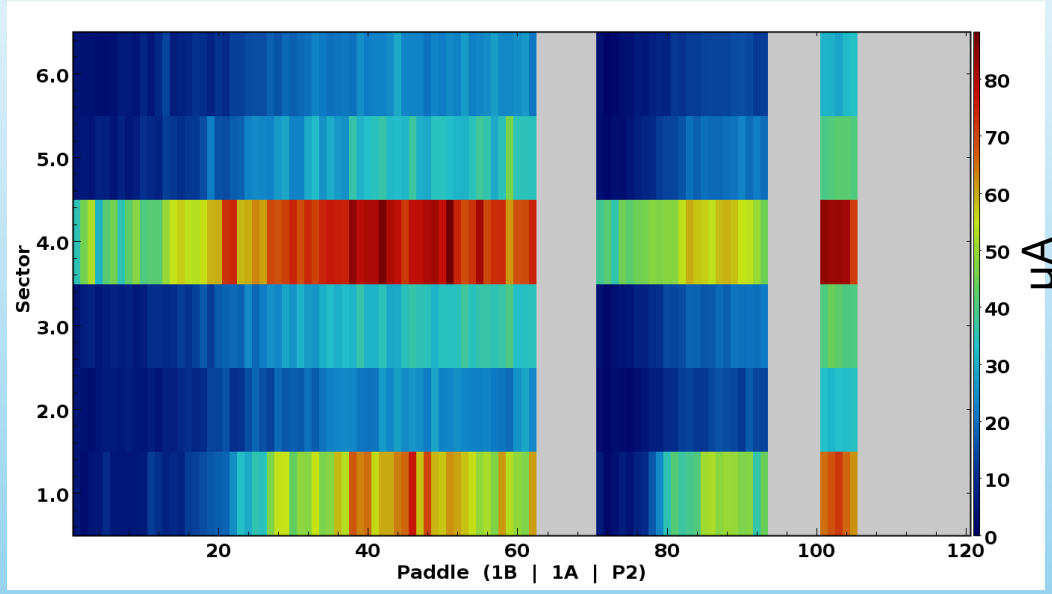
Panel 1A | Panel 1B | Panel 2

RGA

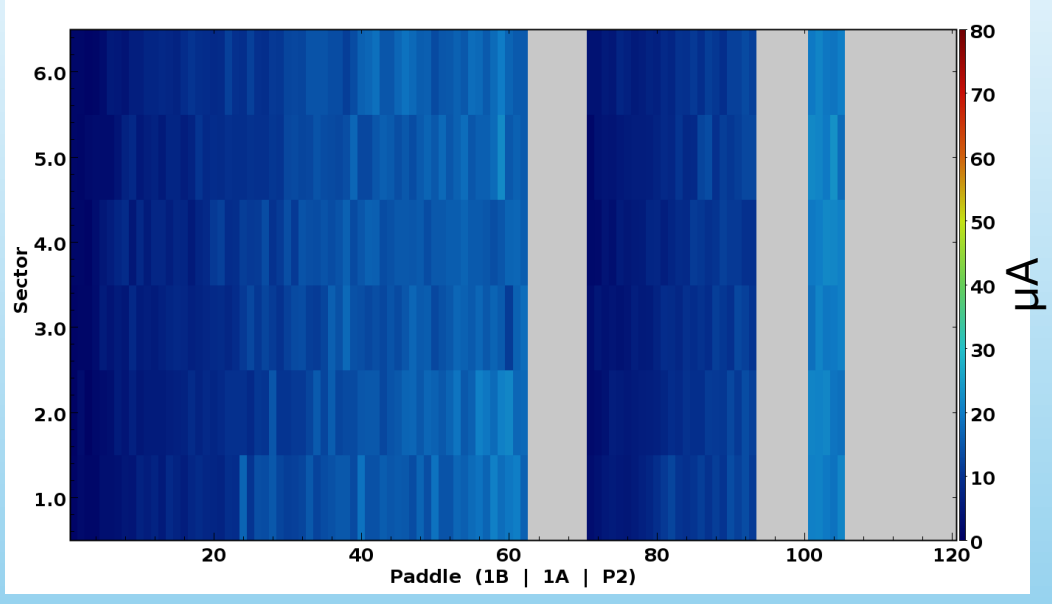


4. FTOF PMT anode current [μA] per paddle and sector

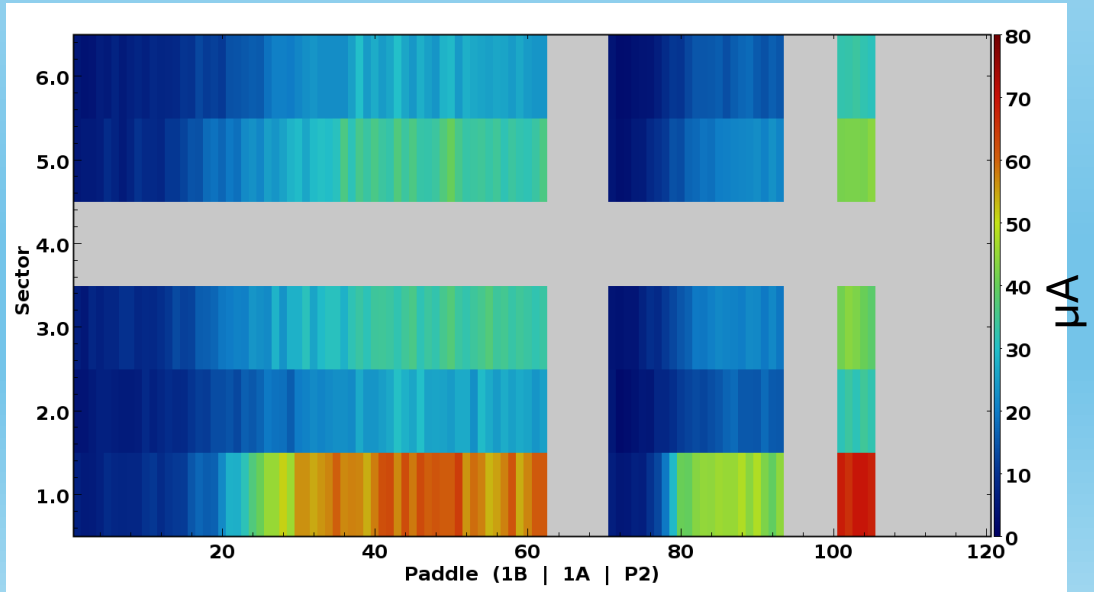
RG-H baseline (ELMO-cone), S4 ON

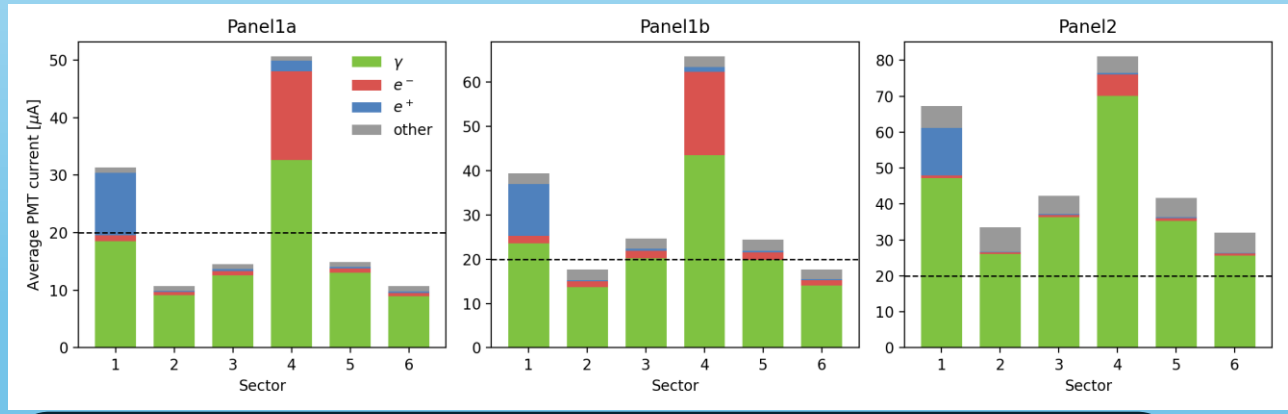


RG-A (inbending, Fall 2018), 75 nA, designed Lumi



RG-H baseline (ELMO-cone), S4 off



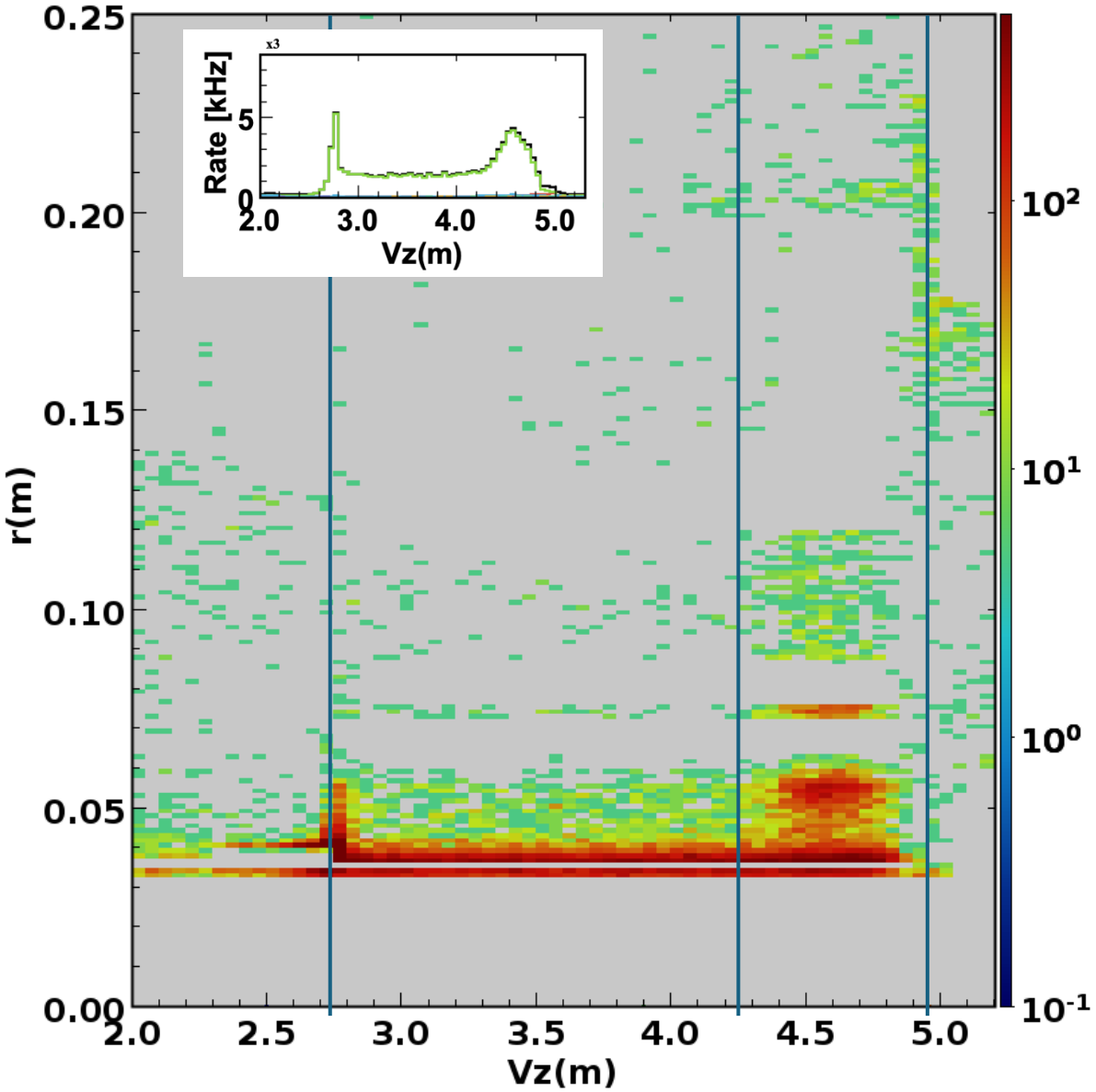


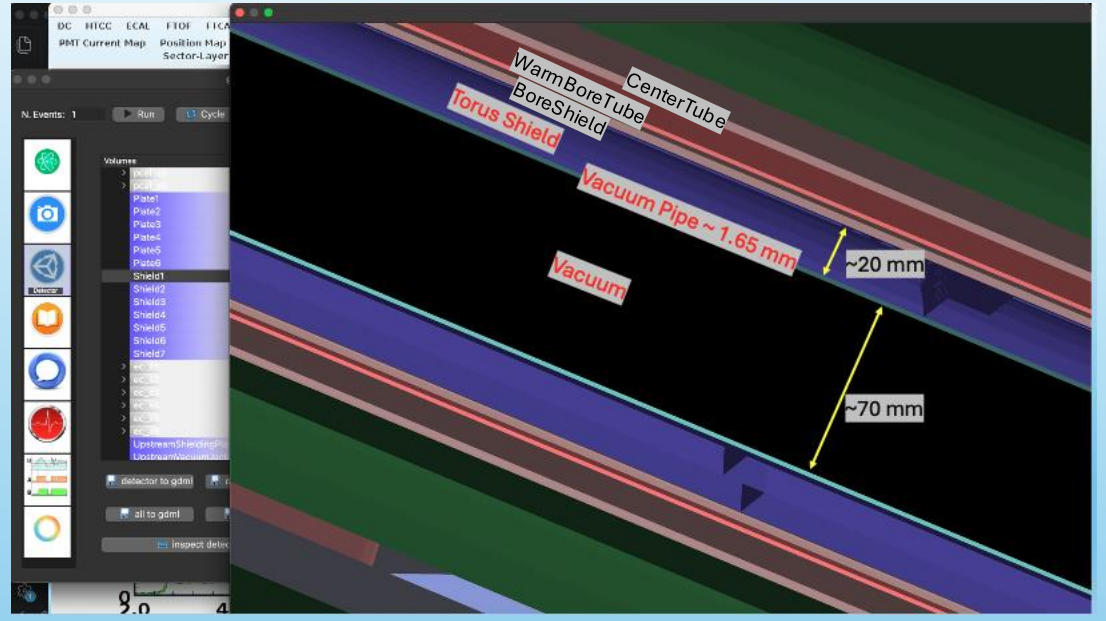
RGH BG Particle Species Breakdown

sector 4's current is dominated by γ + degraded beam e^-; sector 1's excess over the other non-4 sectors is partly target e^+. Turning DC tracking off in sector 4 (bottom-left) has no effect on FTOF , it's a separate subsystem seeing the same background.

5. FTOF Origin of BG at Torus Region Beamline Components

RGH No Sec 4, panel 1B



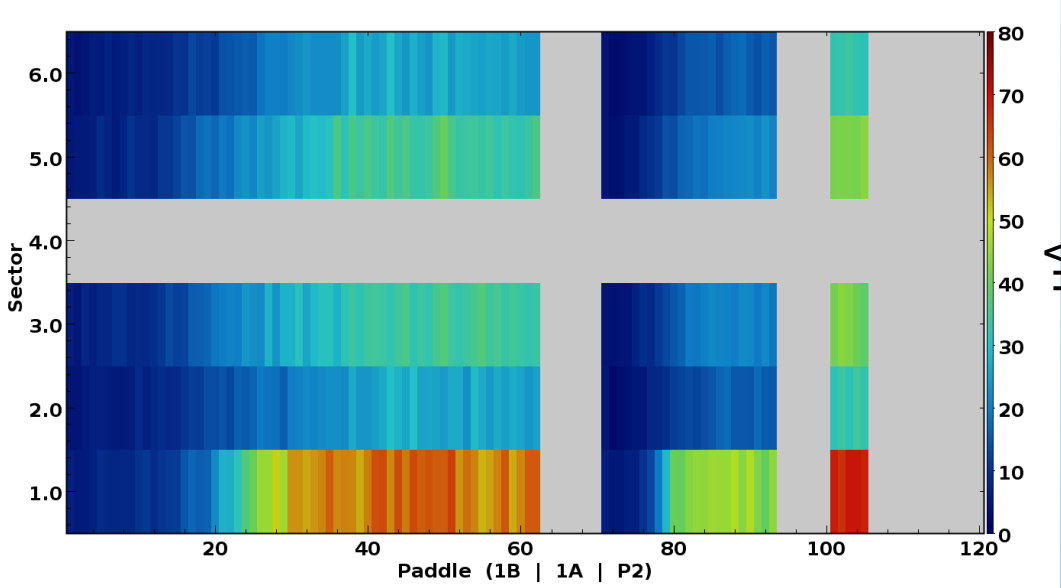


Layer	Material	r_inner (mm)	r_outer (mm)	Thickness
Beam vacuum	G4_Galactic	0	33.274	–
Vacuum pipe wall	G4_SS	33.274	34.925	1.65 mm
Air gap	fc air	34.925	36.8	1.875 mm
Shield1–7	beamline_W (tungsten)	36.8	56.8	20 mm = 2 cm
Tiny gap	fc air	56.8	57.1	0.3 mm
BoreShield	G4_SS	57.1	60.3	3.2 mm
Gap	fc air	60.3	61.9	1.6 mm
WarmBoreTube	G4_Al	61.9	63.5	1.6 mm

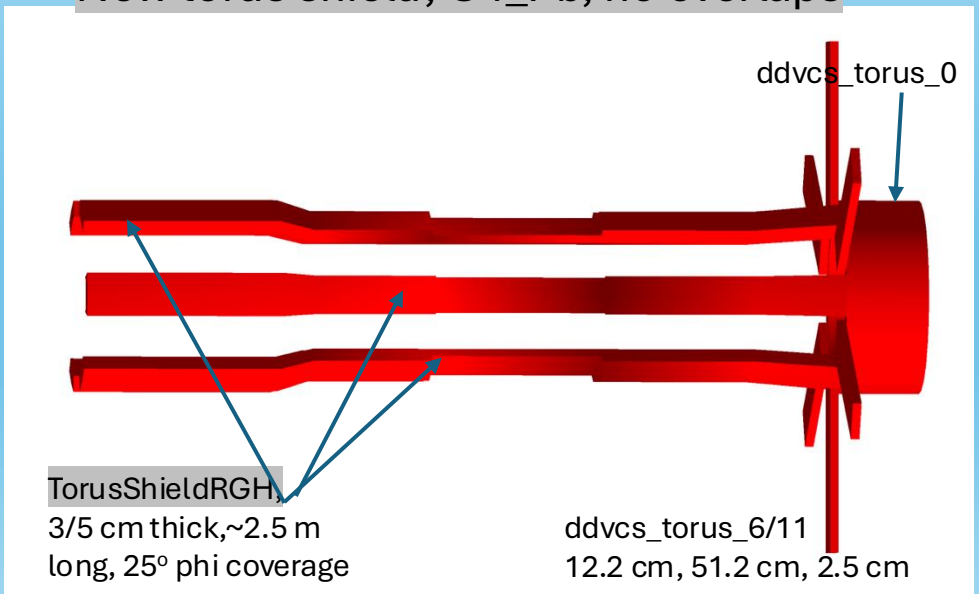
WarmBoreIR = 123.8/2.0 ~ 62.0 mm

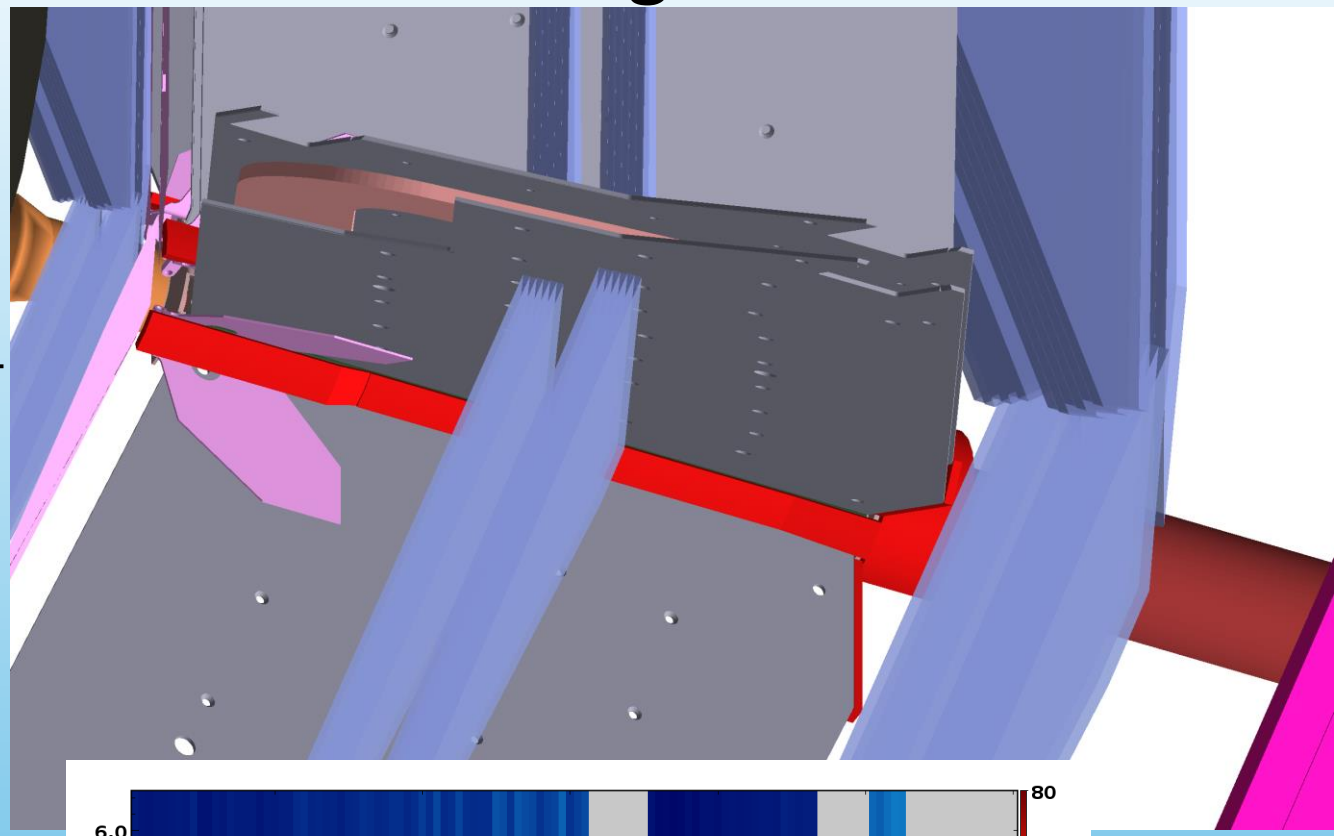
5. FTOF PMT anode current and New Torus Shielding

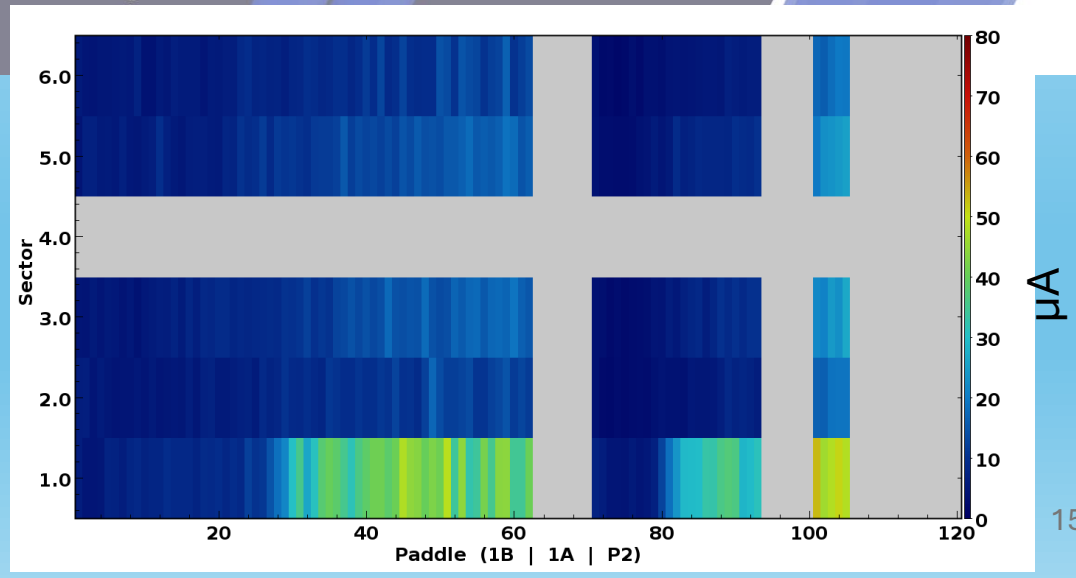
RG-H baseline (ELMO-cone), s4 off



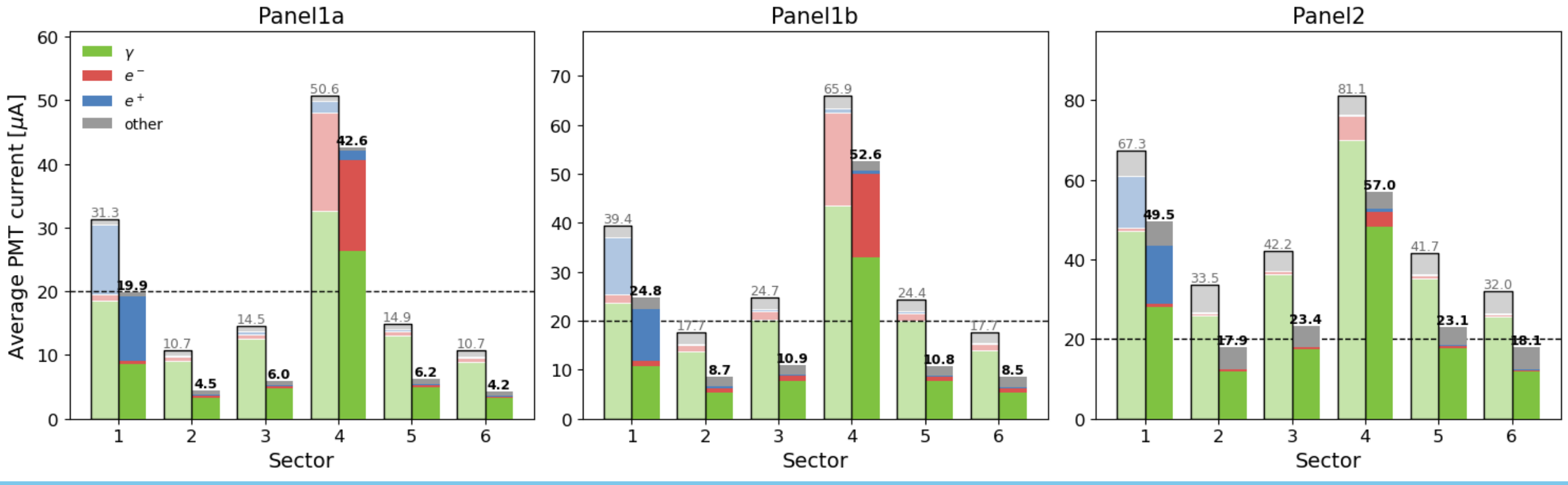
New torus shield, G4_Pb, no overlaps





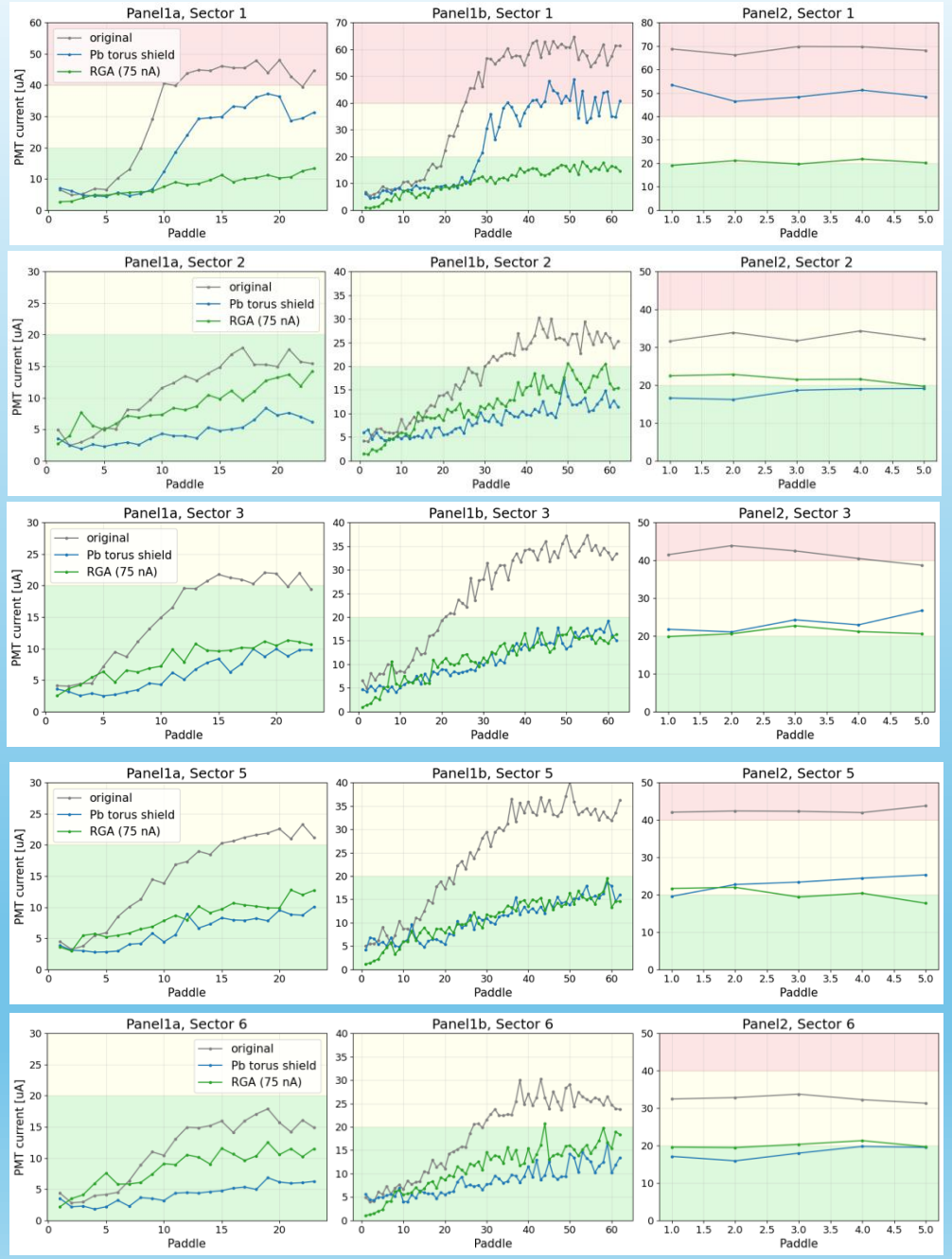


5. FTOF PMT anode current and New Torus Shielding



New torus shield reduces all 5 sectors significantly, brings all but sector 1 below the 20 μA threshold sector average except sector 1.

5. FTOF PMT anode current and New Torus Shielding

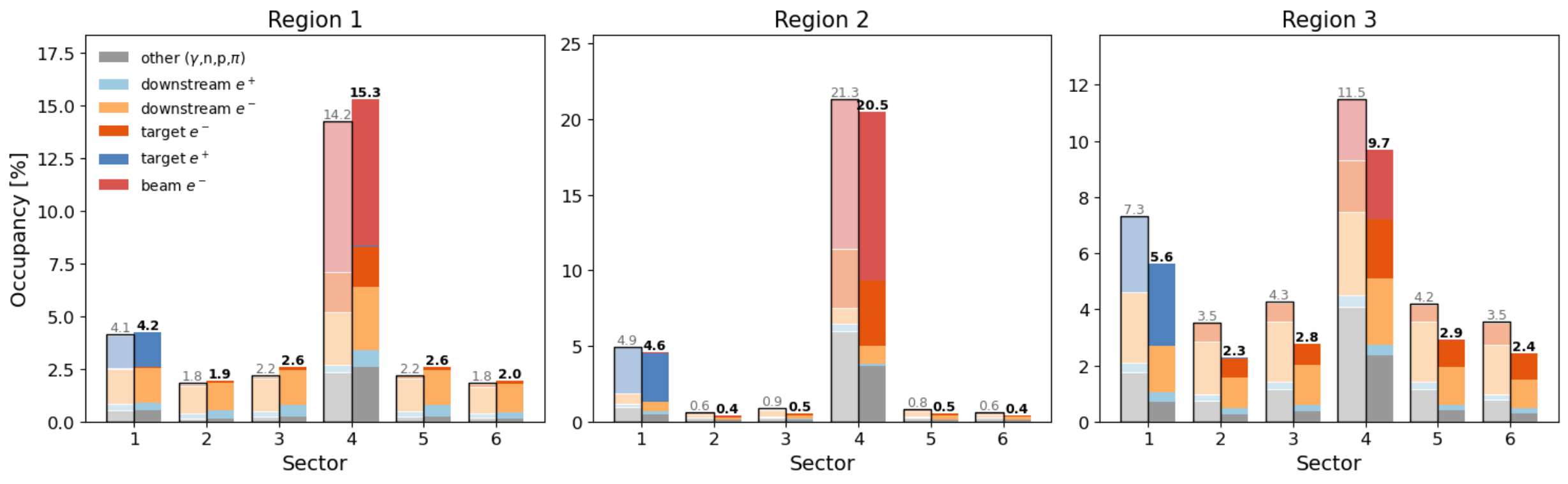


Labels:
RGH original baseline (gray), Pb torus shield (blue), RGA 75 nA (green). Bands: ≤20/20–40/>40 μA.

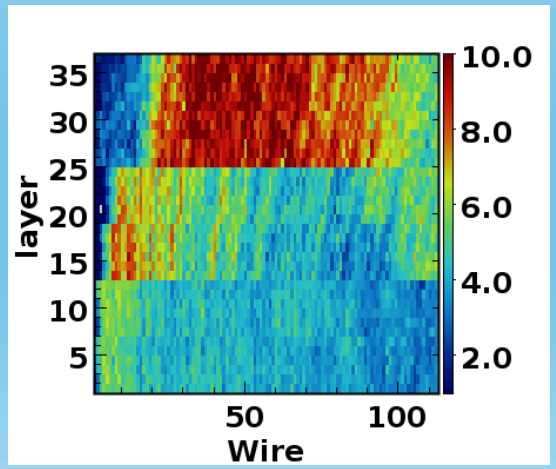
A complementary lever:
PMT HV: cutting HV by ~185 V is estimated to roughly halve the anode current (from the PMT/divider's gain–HV power-law relation).

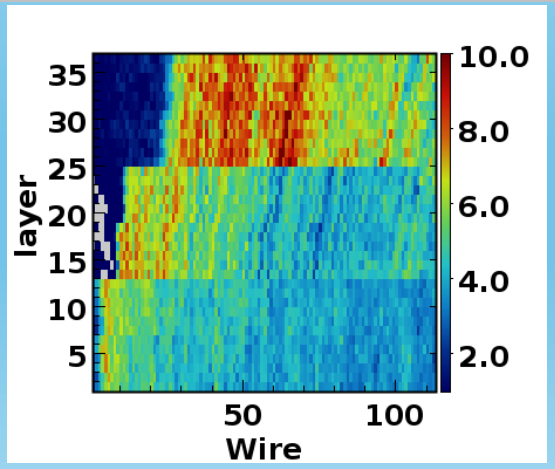
Open question: how much timing/energy resolution is lost, and how much of that is recoverable by retuning ADC/TDC thresholds.
(FTOF Expert DS Carman's presentation)

5. DC Regions Occupancies with New Torus Shielding

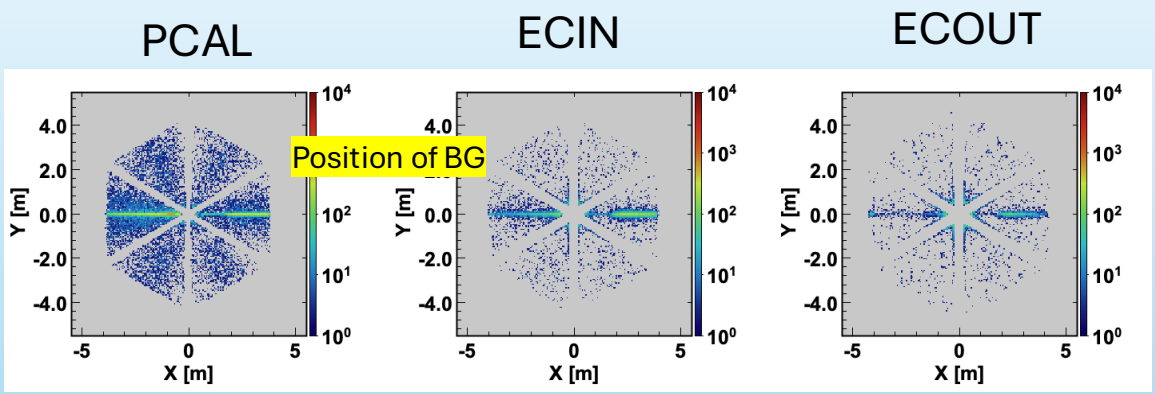


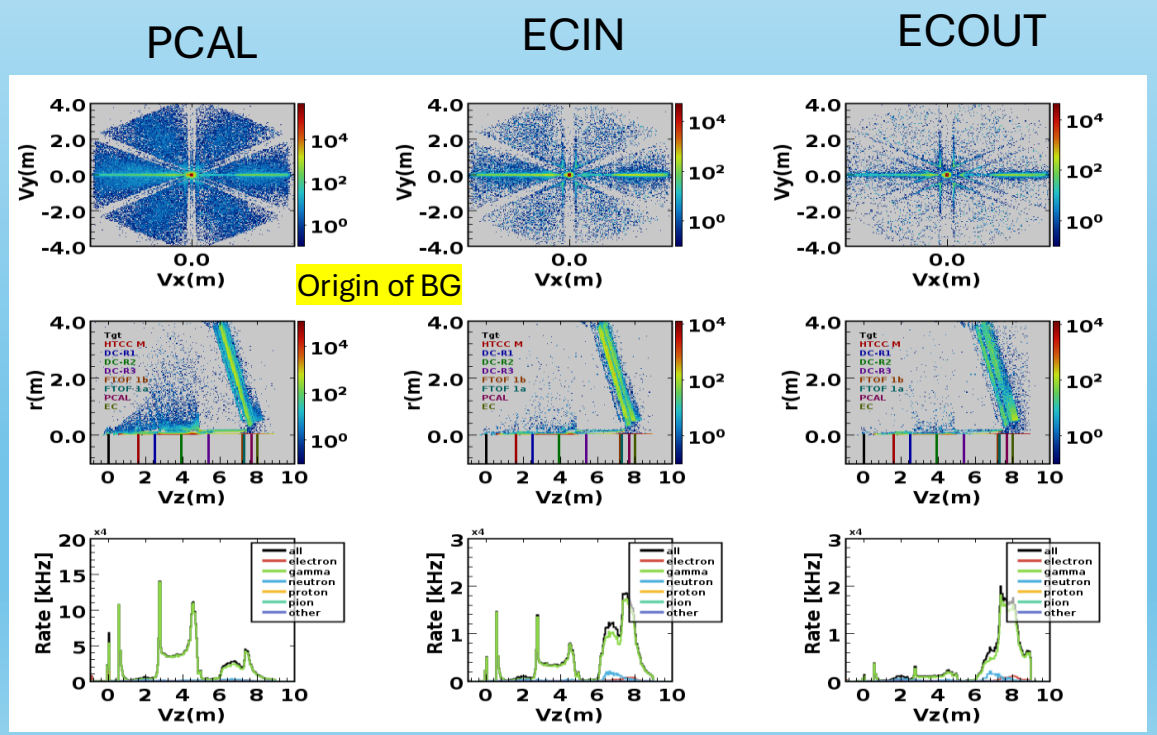
Dc region Sector 1 occupancies without (left) vs with (right) Torus Shielding

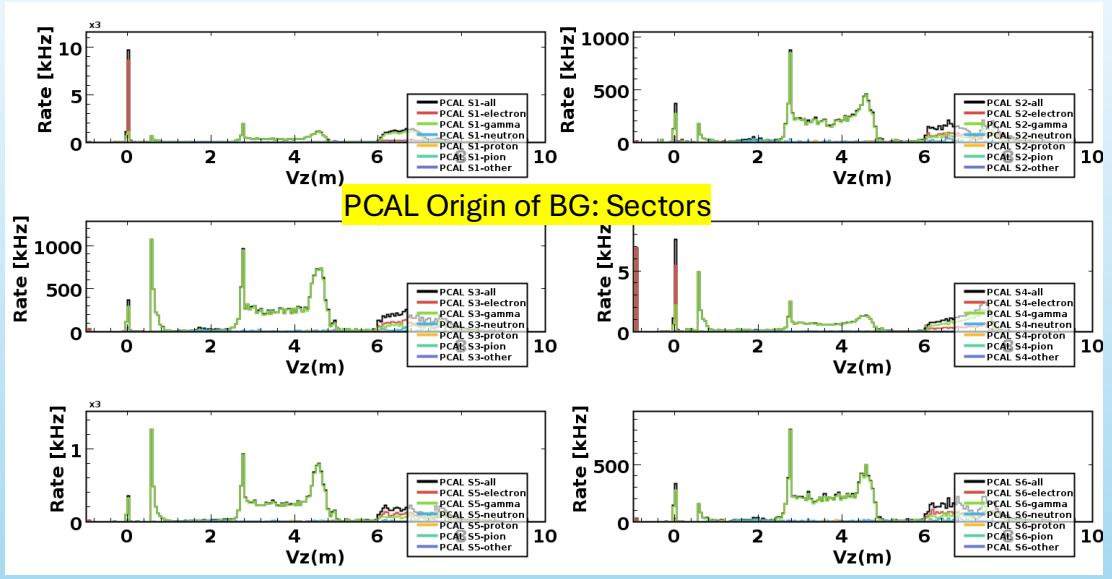


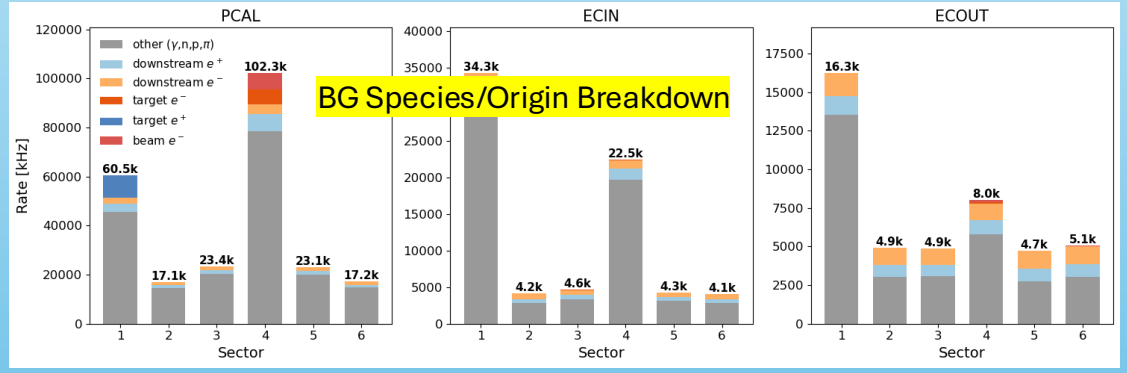


6. ECAL Background rates





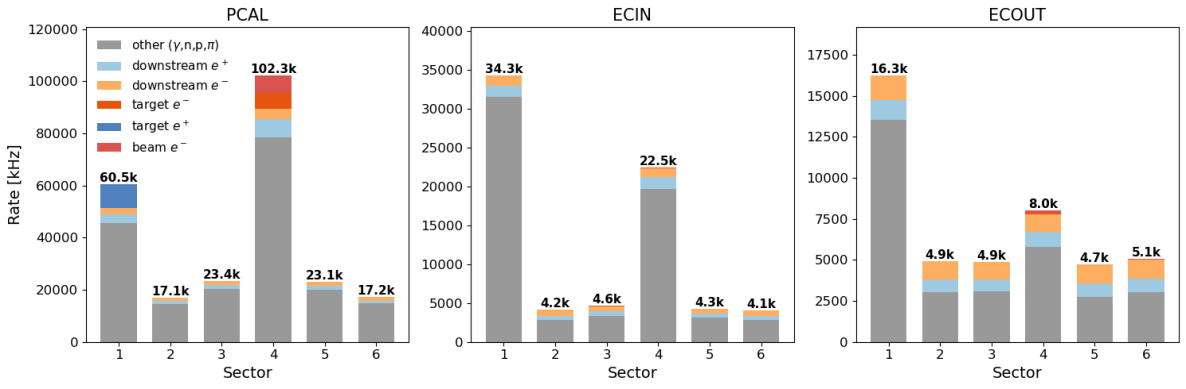




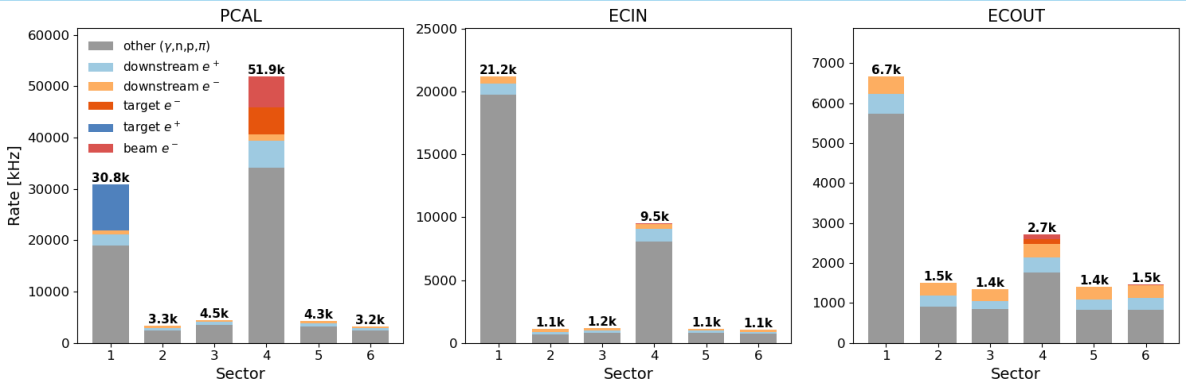
- ECAL (PCAL+ECIN+ECOUT), all sectors:
  - gamma 77% · electron 11% · positron 10% · n/p/π ~3%
  - e^-+e^+ combined = 21% of all background - 79% is non-electron
- Sector 1 (PCAL): mostly γ; its largest e± part is target e^+ (pair production), ~15%
- Sector 4 (PCAL): the only sector with a sizeable “beam e−” component, still a minority of that sector's total.

6. ECAL Background rates Comparisons

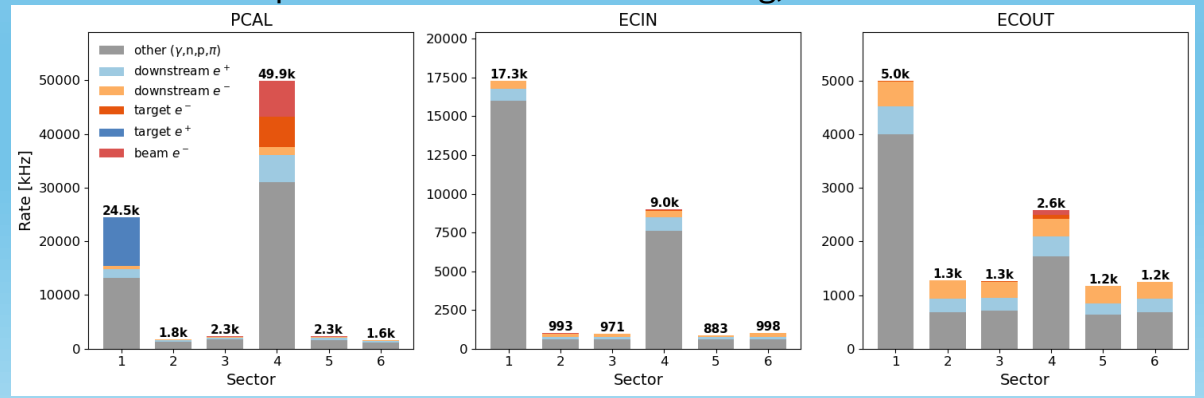
Sector Vs Strip rate RGH baseline, 1 MeV threshold



Sector Vs Strip rate RGH baseline, 3MeV threshold



Sector Vs Strip rate RGH with Torus Shielding, 3MeV threshold



- ECAL rates depend strongly on threshold (1 vs 3 MeV: it's a per-hit energy-deposit cut: each individual ECAL hit's not a summed/cluster energy.)
- Torus shielding reduces the photon BG, but sector 1 stays dominated by target-region e^+ : unaffected by the torus shield.
- A different, target-area shield would be useful there.

6. The CLAS12 Electron Trigger

What changes when RGH replaces the solenoid with a 5 T transverse target field

HTCC × PCAL × E(total) = PCAL+EC × DC (OR over sectors 1-6)

Nphe> 2 p.e. | PCAL E>60 MeV | E(total) > 150/300 MeV | ≥3/6 layers, ≥5/6 superlayers, road matched to ECAL cluster; source: CLAS12 Trigger NIM A 960 (2020)

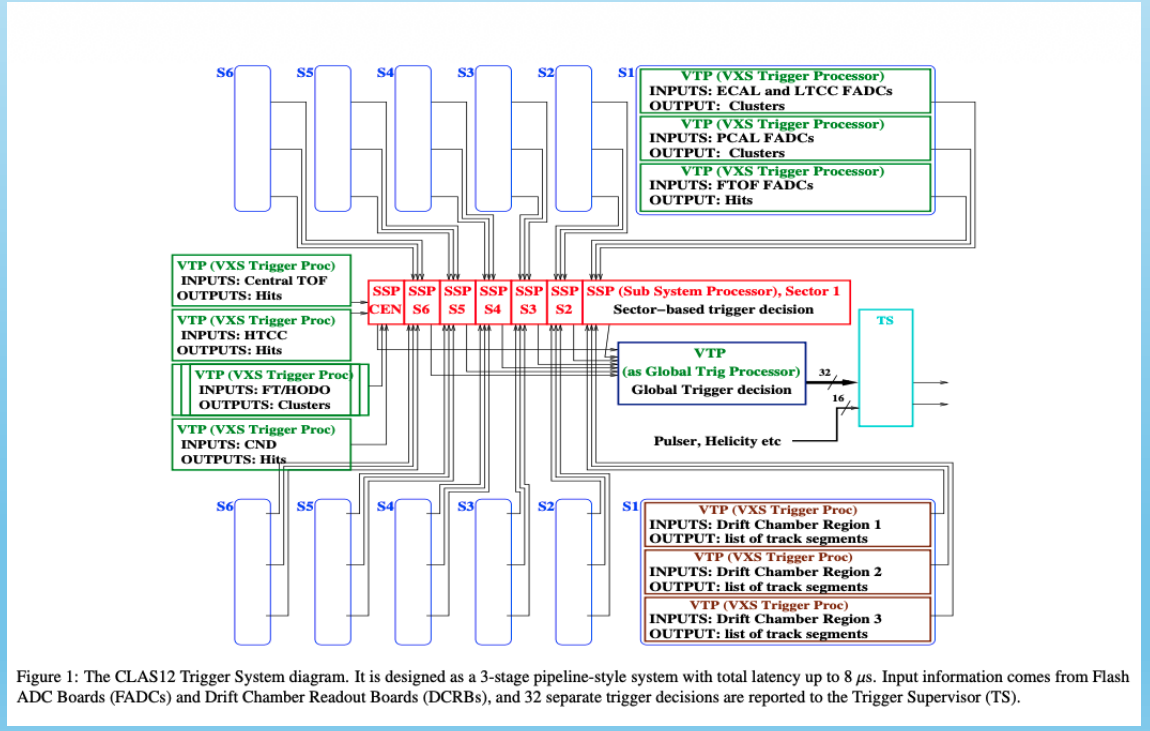


Figure 1: The CLAS12 Trigger System diagram. It is designed as a 3-stage pipeline-style system with total latency up to 8 μs. Input information comes from Flash ADC Boards (FADCs) and Drift Chamber Readout Boards (DCRBs), and 32 separate trigger decisions are reported to the Trigger Supervisor (TS).

What Changes for RGH

Luminosity 5×10^{33} cm^{-2}s^{-1} (~1 nA) — 20× below CLAS12's nominal 10^{35}

NH_3 DNP target, 5 T transverse field inside HTCC

Solenoid parked, Central Detector removed — Recoil detector (3 µRwell trackers + TOF) added instead

No FT, CTOF, or CND trigger primitives

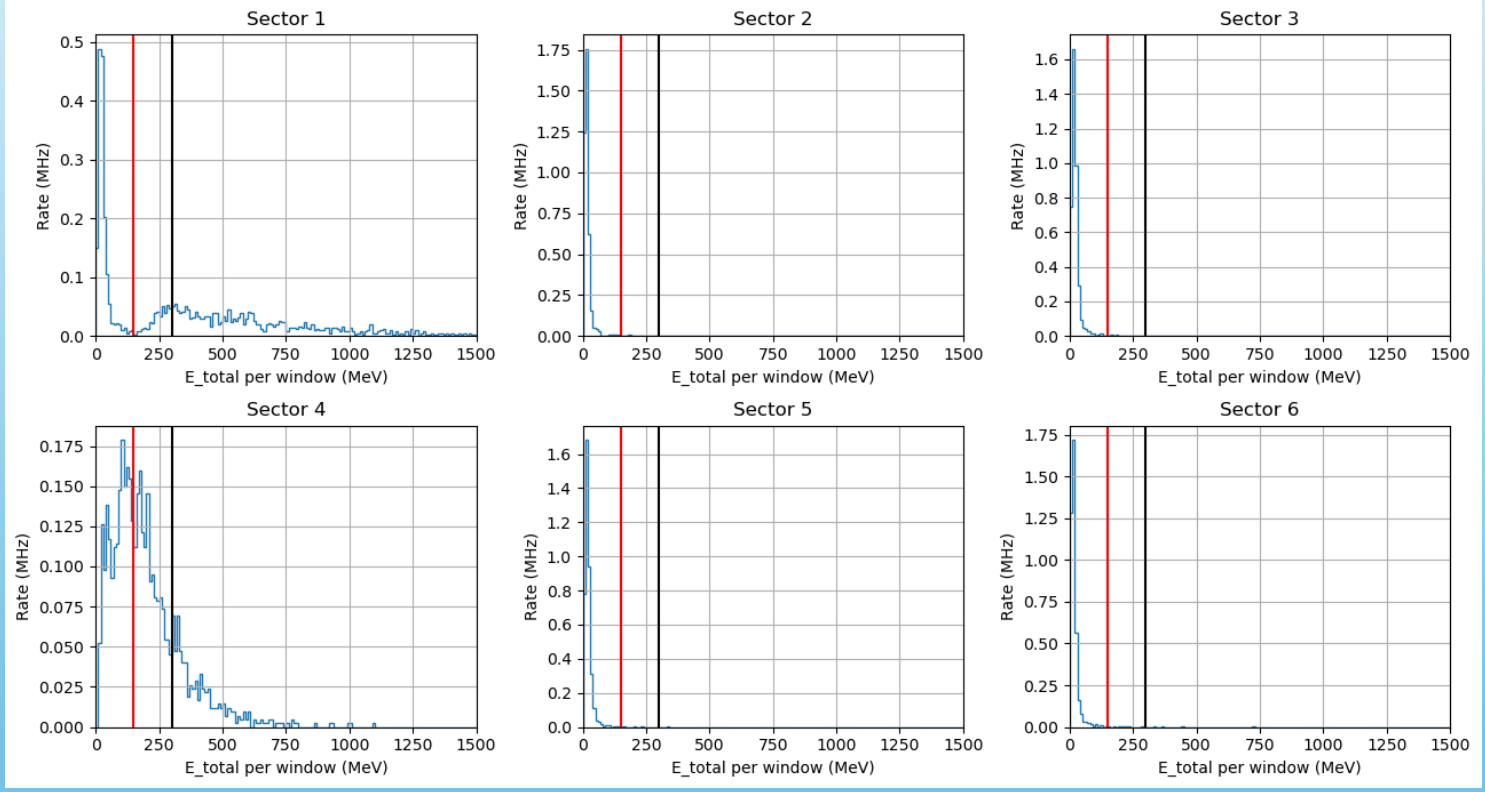
Sector 4: DC off (sheet-of-flame) — no DC road condition there

Goal: electron-trigger efficiency > 99% for E' > 1.5 GeV

(Trigger System Expert Valery Kubarovsky's presentation)

6. ECAL Trigger-Threshold Check: E(total) vs 150/300 MeV

E_total = PCAL+ECIN+ECOUT per sector per 252 ns window; 10 MeV bins; red = 150 MeV, black = 300 MeV.



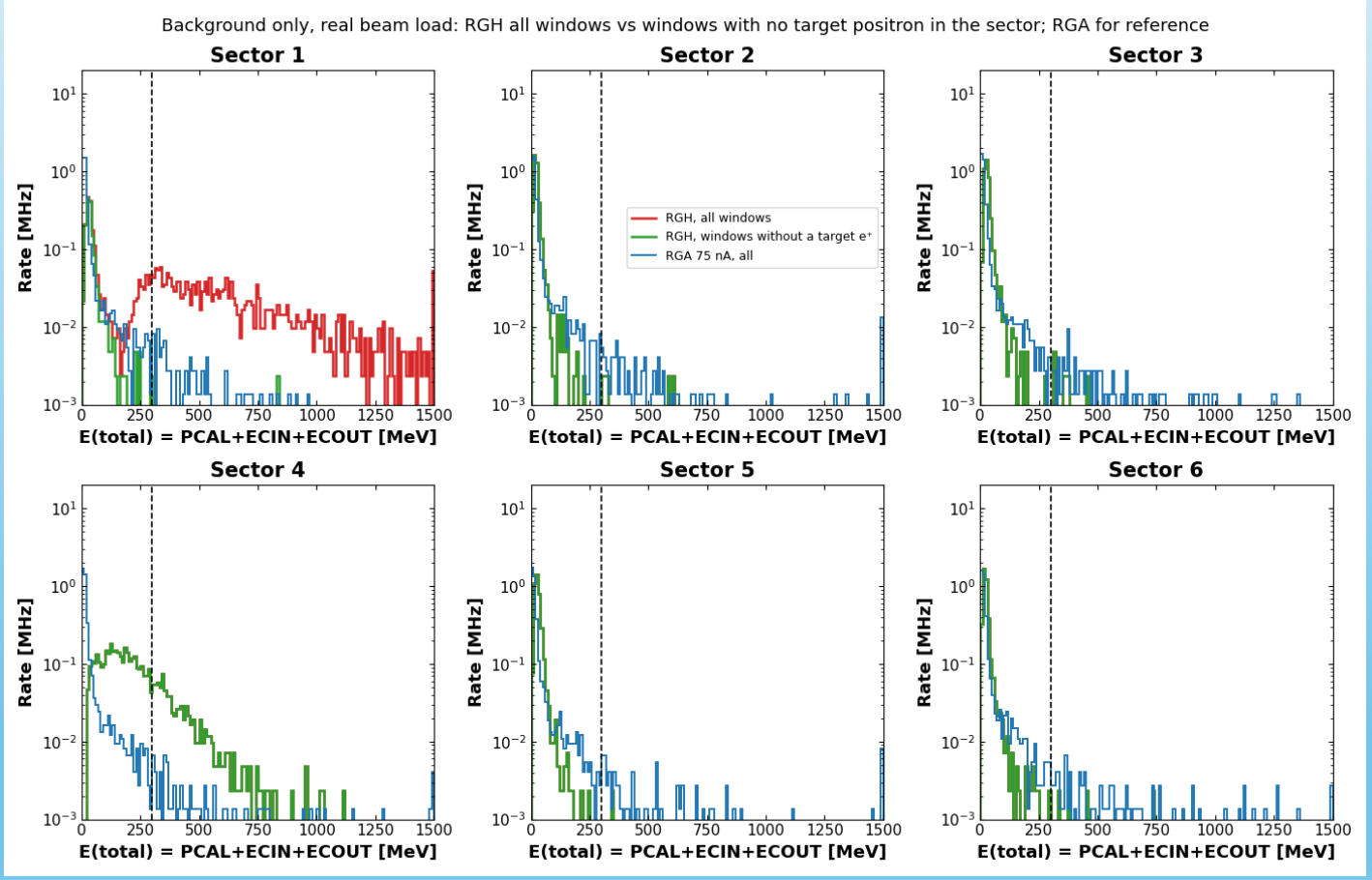
Exceed-rate: how often background alone pushes a sector over threshold.

Sector	E(total) > 150 MeV [MHz]	E(total) > 300 MeV [MHz]
1	**2.375**	**2.034**
2	0.029	0.012
3	0.029	0.014
4	**2.422**	**0.846**
5	0.019	0.002
6	0.038	0.010

Background only. The simulation has 450 beam e^- per 252 ns, the real beam at ≈1 nA has 1350, so every 3 simulated events are added together into one realistic 252 ns window.

Sector 1 Is a Target-Positron Problem

E(total) per sector per window - RGH all (red), RGH with target e^+ removed (green), RGA (blue)



Rate [MHz], E(total)>300 MeV & PCAL>60 MeV, background only

Sector	RGH all	no e^+	RGA
1	2.034	0.002	0.067
2	0.007	0.007	0.083
3	0.014	0.014	0.079
4	0.846	0.846	0.070
5	0.002	0.002	0.071
6	0.005	0.005	0.079

Sector 1: removing target-e^+ windows drops 2.03 → 0.002 MHz, below RGA's ~0.07 MHz reference.

Assuming the DC road fully rejects positive tracks, to be confirmed with the trigger expert.

Target e^+ window: a positron from |Vz|<10 cm (or its shower) deposits >1 MeV in that sector's ECAL.

7. Summary and Outlook

Key findings from the RGH background studies:

DC

- Sector 4 dominated by degraded beam e^- (sheet-of-flame);
- Sector 1 background has a fraction from target e^+ component.
- Outside sector 4, RGH occupancy tracks RGA , except Region 3, which runs higher across every sector.
- ELMO "Mix" chosen over better-performing "Wide" due to its overlap with the HTCC Moller cone.
- New torus shield helps Region 3 occupancy; Region 1 is largely unchanged.

ECAL

- Background is photon-dominated overall (77% γ), e^-+e^+ combined are 21%.
- Sector 1's electron/positron share is dominated by target e^+ (pair production).
- Torus shielding cuts the photon background but doesn't touch sector 1's target-e^+ problem.

HTCC

- Ring1 background-hit probability is large (NPhe>0), which drops to ~5% once sector 4 is excluded.
- Per-PMT rates stay non-negligible even outside sector 4.
- Accidental HTCC+ECAL coincidence impact remains open.

FTOF

- PMT currents exceed acceptable limits in the baseline config, torus-region photons dominate all three panels.
- New torus shielding cuts FTOF rate and PMT current by more than 50%, bringing sectors 2, 3, 5, 6 below 20 μA.
- Sector 1 stays above that limit, its excess comes from target-region positrons, not torus photons.
- PMT HV reduction is a possible complementary fix.

Trigger

- Background alone pushes sector 1 past E(total)>300 MeV at ~2.0 MHz.
- DC-road charge selectivity can be used to reject target e^+.
- Sectors 2, 3, 5, 6 already sit below the RGA reference.

Outlook:

- Finalize the ELMO design and discuss the feasibility of torus shielding with the engineering group
- Work with experts to reduce FTOF rates and PMT currents to acceptable levels
- Complete the check of background impact on the trigger system, working with the trigger experts
- Check reconstruction efficiency with physics simulations that include background.

Thank You!

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6.3 PMT Rates and Currents

The critical operational constraint for FTOF is the average PMT anode current. It should stay below the acceptable limit to keep the gain stable, to get good quality data, and to avoid fast PMT aging [7, 8]. We estimate the average current per PMT from the simulated energy deposit, following the method of Daniel Carman [8]. A particle that deposits energy E_{dep} in a paddle makes $E_{\mathrm{dep}}\,Y$ photoelectrons at the photocathode. Each photoelectron gives a charge $Q_e\,G$ at the anode. The average current is this charge per unit time:

$$I\,[\mu\mathrm{A}] = \frac{\sum E_{\mathrm{dep}}\,[\mathrm{MeV}] \;\times\; Y\,[\mathrm{phe/MeV}] \;\times\; 1.6\times10^{-7}\,[\mu\mathrm{C/phe}]}{T\,[\mathrm{s}]} \tag{2}$$

Here the sum runs over all hits in the paddle during the time T, the symbols are listed in Table 7, and the photoelectron yield Y used for each panel is given in Table 8. Equivalently, $I = \langle E_{\mathrm{dep}}\rangle\, Y\, Q_e\, G\, R$, where R is the hit rate of the paddle and $\langle E_{\mathrm{dep}}\rangle$ is the mean energy per hit.

Symbol	Description
I	Average PMT anode current [μA]
$\sum E_{\mathrm{dep}}$	Energy deposited in the scintillator paddle, summed over all hits [MeV] (from `MC::True::totEdep`)
T	Beam time represented by the simulated events [s]
Y	Scintillator photoelectron yield [phe/MeV]
1.6×10^{-7}	Charge per photoelectron at the anode [μC/phe] (electron charge $\times$ gain $G = 1\times10^{6}$, in μC)

Table 7: Symbols in the PMT current estimate formula (Eq. 2). Y is the net *photoelectron* yield at the photocathode. Note that 1 μC/s = 1 μA.

Panel	$N_{\mathrm{phe,ref}}$ [phe]	ΔE_{ref} [MeV]	Y [phe/MeV]	Counters
P1a	373	10	37.3	BC-408, EMI/Philips PMTs
P1b	1158	12	96.5	BC-404/BC-408, Hamamatsu R9779
P2	373	10	37.3	BC-408, Photonis PMTs

Table 8: Panel-specific values from Carman's FTOF current note [8], as quoted in the CLAS12 FTOF paper [7].

https://www.jlab.org/Hall-B/ftof/notes/ftof_currents.pdf
https://github.com/mariangelabondi/clas12_simulation_rootMacro/blob/main/tof_trigger.C

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Torus Shield Volume and Cost Estimates

Part	Shape	z range [mm]	r_{in} [mm]	r_{out} [mm]	Thickness [mm]
Wedge, seg. 1	polycone, 25°	2670 – 3250	248	298	50
Wedge, seg. 2	(slope)	3250 – 3350	248 → 214	298 → 264	50
Wedge, seg. 3		3350 – 3700	214	264	50
Wedge, seg. 4	(thin)	3700 – 4200	214	244	30
Wedge, seg. 5		4200 – 4650	214	264	50
Wedge, seg. 6	(slope)	4650 – 4908	214 → 238	264 → 288	50
Ring (`ddvcs_torus_0`)	polycone, 360°	4908 – 5150	238	288	50
End plate (`ddvcs_torus_11–16`)	box, ×6	4882 – 4908	$r \approx 248 - 760$		25.4

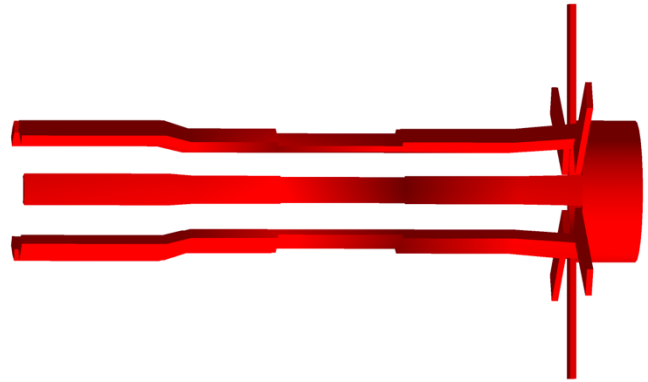
Table 9: Geometry of the new torus shielding. One wedge is shown (the five active wedges at sectors 1, 2, 3, 5, 6 share this profile, each covering a 25° slice at its nominal 60°-spaced position); the wedge alone is about 2.24 m long in z, and the full shield including the ring reaches $z = 5.150$ m (2.48 m long). The end plates are boxes of 122.6 mm (azimuthal) × 512 mm (radial) × 25.4 mm (z), centered at $z = 4895.1$ mm and 504 mm from the beamline axis.

Component	Qty	Volume (L)	Mass, Pb (kg)	Mass, W (kg)
Wedge	5	55.5	630	1,068
Downstream ring	1	20.0	227	385
End plate	6	9.6	109	184
Total		**85.1**	**966**	**1,637**

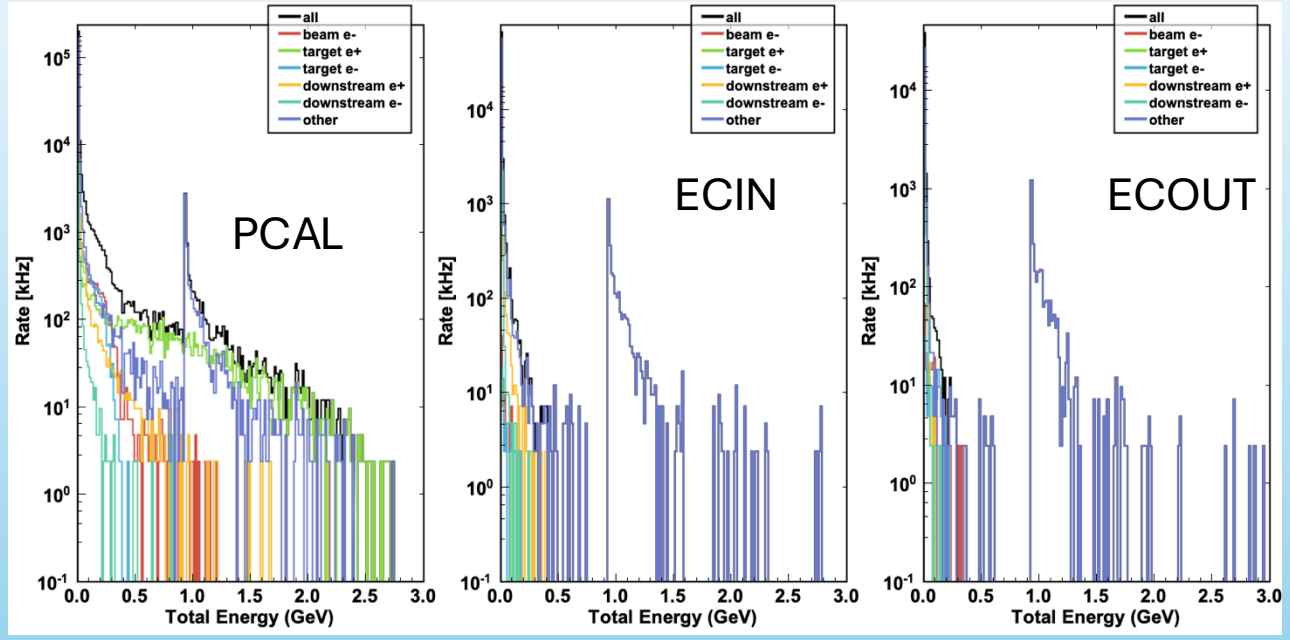
W ~1.7 × denser than Pb

Rough cost estimate (raw material only)

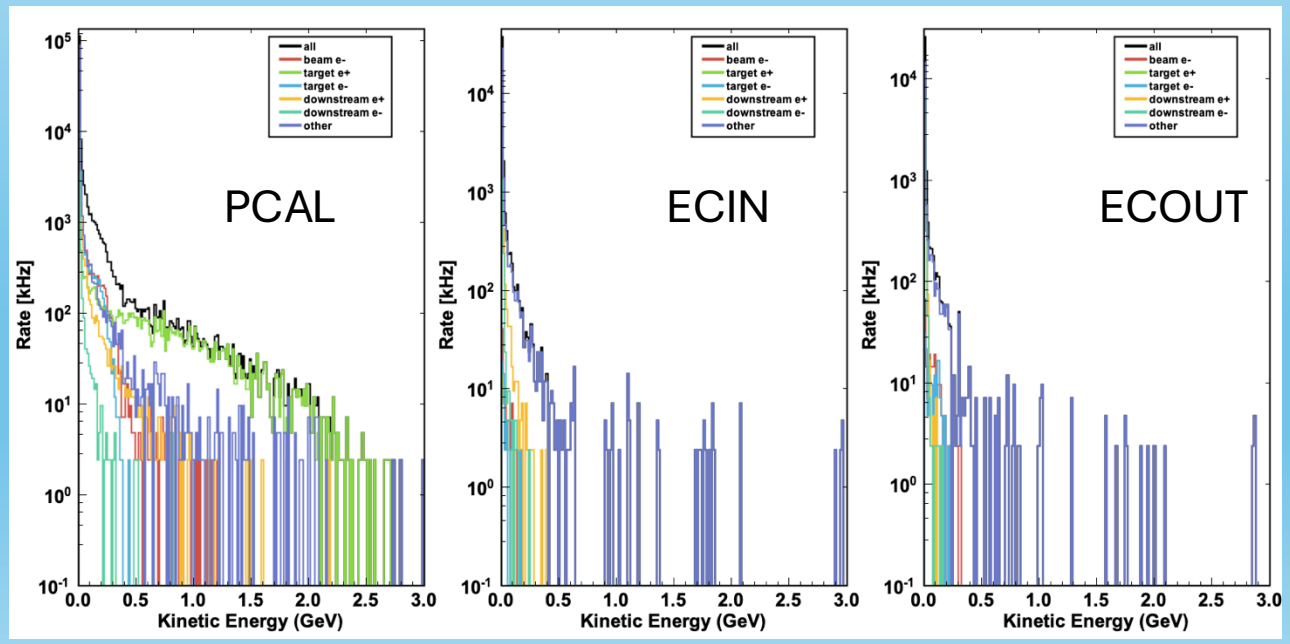
Material	Mass (kg)	Low ($/kg)	High ($/kg)	Low total ($)	High total ($)
Lead (Pb)	966	$1.80	$2.50	$1,739	$2,415
Tungsten (W)	1,637	$30.00	$45.00	$49,110	$73,665



6. ECAL **Trigger-Threshold Check:** Kinetic and Total energy of 3 ECAL Layers



The total Energy Spectrum plots use **t.getEnergy()** the true underlying particle's own energy from GEANT4 truth. $\mathbf{E = \sqrt{(p^2 + m^2)}}$.

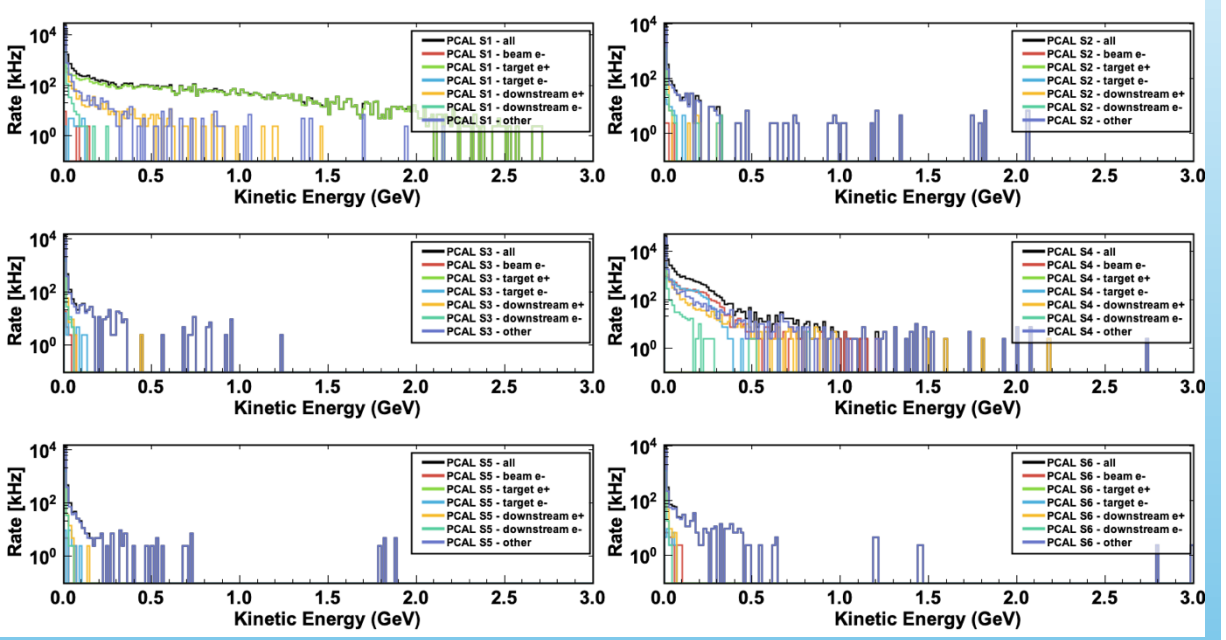


The Energy Spectrum plots use **t.getKinEnergy()** the true underlying particle's own energy from GEANT4 truth.

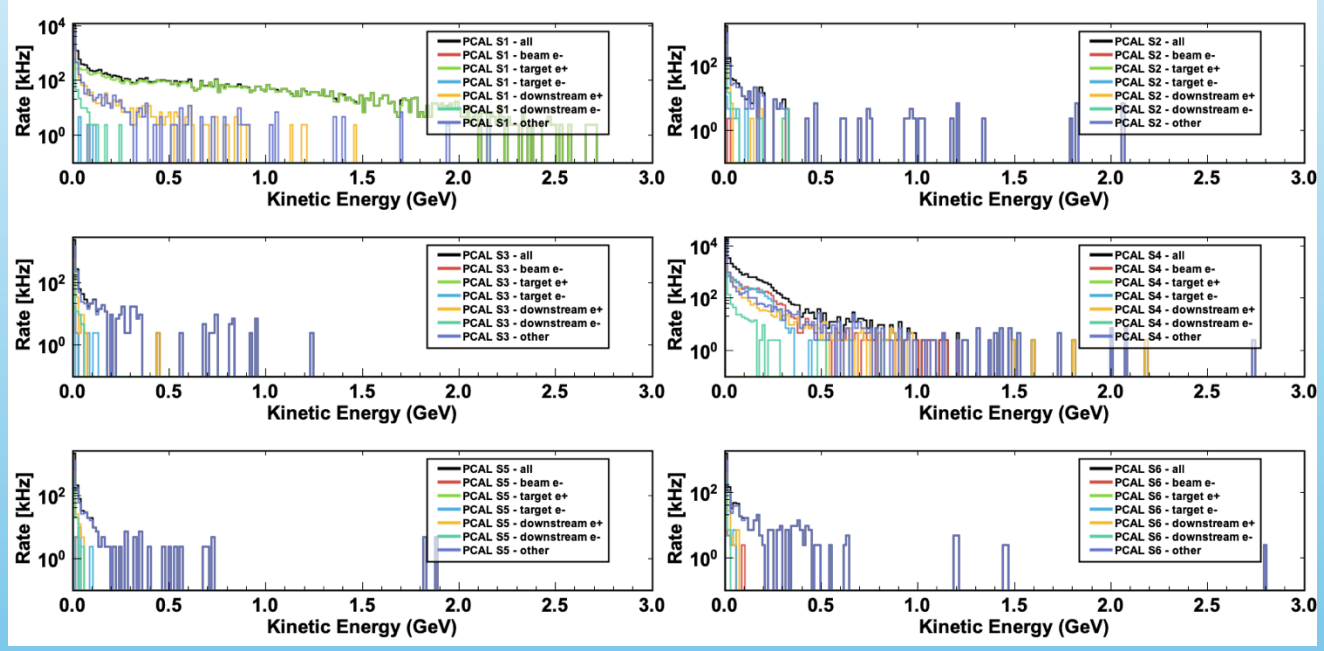
K.E. = E – m

6. ECAL **Trigger-Threshold Check:** Kinetic energy of PCAL Sectors

1 MeV Threshold



3 MeV Threshold



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RGH BG Simulations

Luminosity=1350 normalization: 1350 e^-/252 ns → I = 0.8582 nA → L ~ 5e+33 $cm^{-2}s^{-1}$
CLAS12 reference : I = 75.0 nA → L = 9.90e+34 $cm^{-2}s^{-1}$

Table 5: GEMC volume definitions for the RGH transverse polarized target. All dimensions are from the geometry file.

Volume name	Shape	r_{in} (mm)	r_{out} (mm)	Target Length	Material
`ttargetCell`	Tube	0	13.5	28.4 (along Z)	`NH3target`
`al_window_entrance`	Tube	0	13.5	0.025 (endcap)	`G4_Al`
`al_window_exit`	Tube	0	13.5	0.025 (endcap)	`G4_Al`

Target Materials

Table 6: Material definitions used in the RGH target simulation. `NH3target` is the active material assigned to `ttargetCell`.

Material name	Description	Density (g/cm^3)	Composition (mass fraction)
`NH3target`	Active target (NH_3 beads + He bath)	0.5782	89.97 % `NH3` + 10.03 % `lHeCoolant`
`NH3`	Pure solid NH_3	0.867	^{14}N 83.3 % + H 16.7 %
`lHeCoolant`	Liquid He coolant	0.147	^{4}He 100 %
`Kel-F`	Target cell walls (PCTFE)	2.135	C 20.7 % + Cl 30.2 % + F 49.1 %
`carbonFiber`	Structural support	1.75	C 74.5 % + epoxy 25.5 %
`epoxy`	Structural glue	1.16	$H_{32}N_2O_4C_{15}$
`rohacell`	Scattering chamber foam	0.10	C 64.7 % + H 7.8 % + N 8.4 % + O 19.1 %

