



hpDIRC Background Rate Study



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ePIC hpDIRC DSC Group

NP-EXP Group Meeting

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CUA

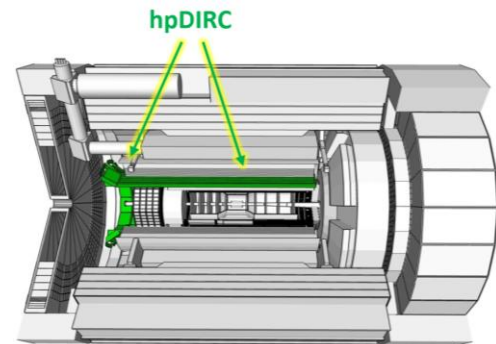


Jefferson Lab



Background Rate for 18×275 Configuration

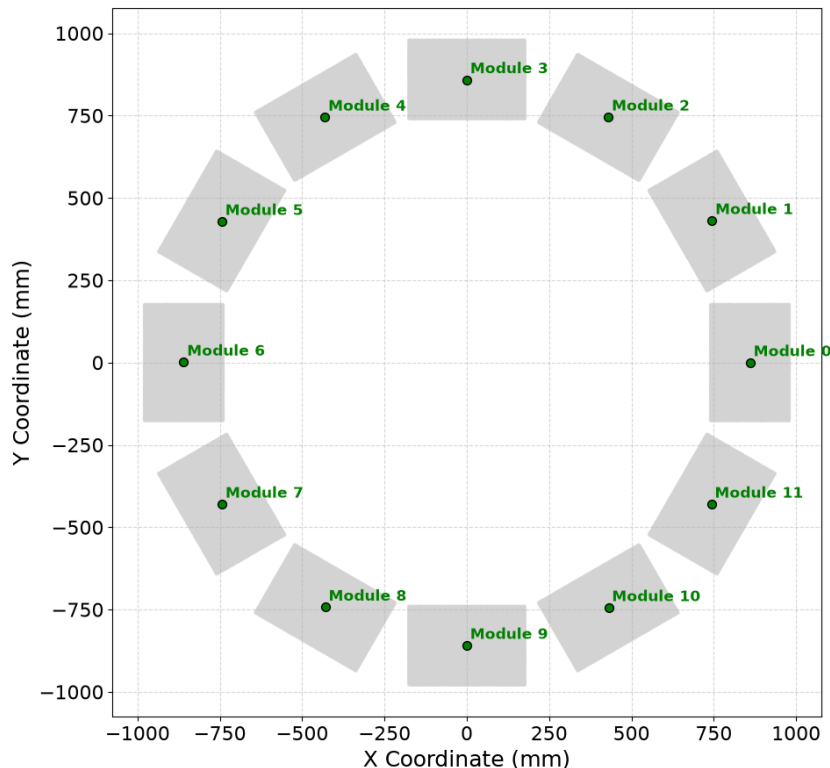
Introduction



- ❖ Estimate hpDIRC background hit rates for the **18×275 configuration**.
In the last update background hit occupancy results were shown ([link](#)).
- ❖ Compare the background contributions with reconstructed SIDIS signals
- ❖ Calculate the hit-rate density, fluence per fb^{-1} and HRPPD integrated anode charge (IAC)
- ❖ First look at background occupancy for **10×275 configuration**
- ❖ **The two known limitations** that affect the results is present as the datasets used were generated before the fix in the simulation framework
 - Fully pixelated detector plane, no gaps or dead areas
 - Current results contain artificial, rare high-multiplicity event anomalies
 - Expect the results **scale down by ~50%** for realistic HRPPD layout and photon detection efficiency

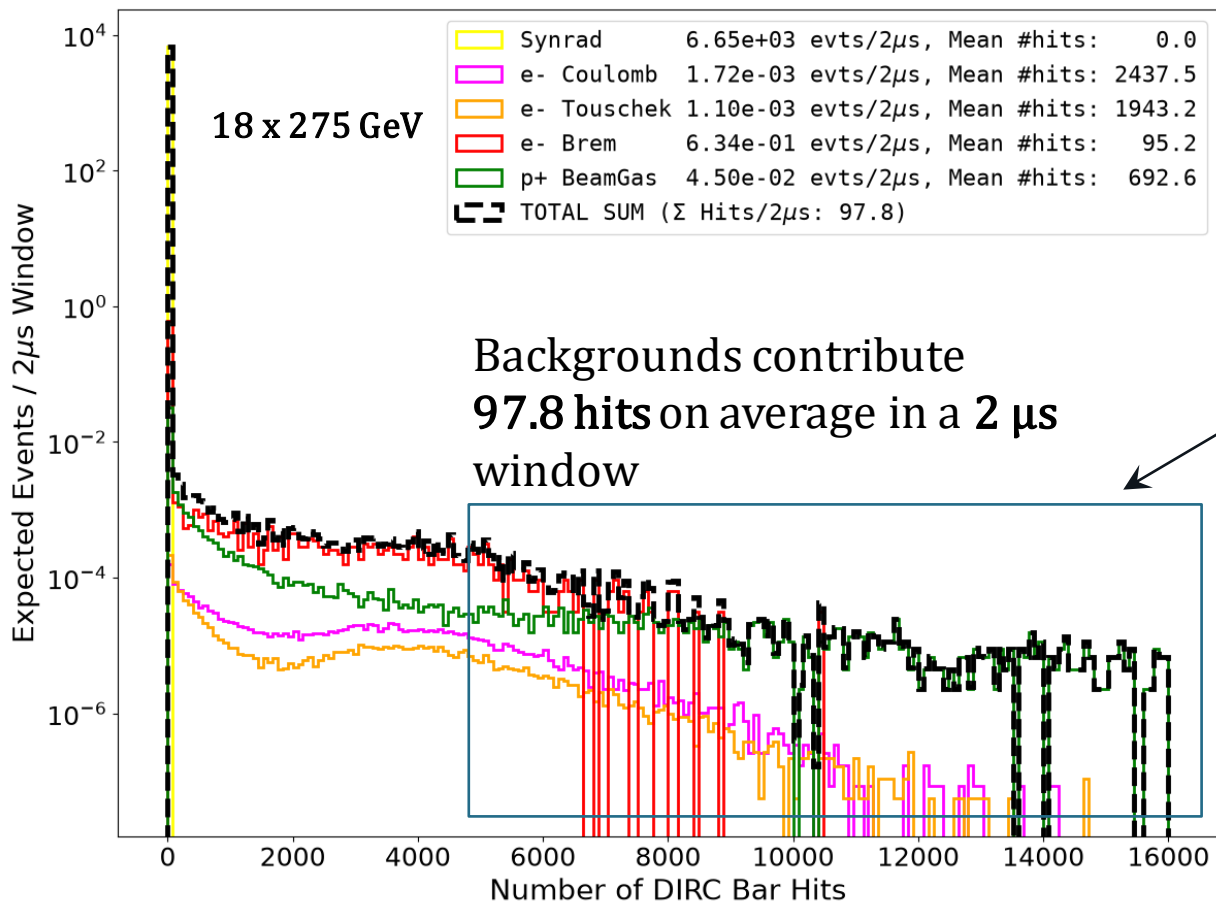
Detector Module Layout

- 12 readout modules, each measuring $35.7\text{ cm} \times 24.3\text{ cm}$
- Each having 9639 pixels of $3\text{ mm} \times 3\text{ mm}$ size (idealized detector plane)



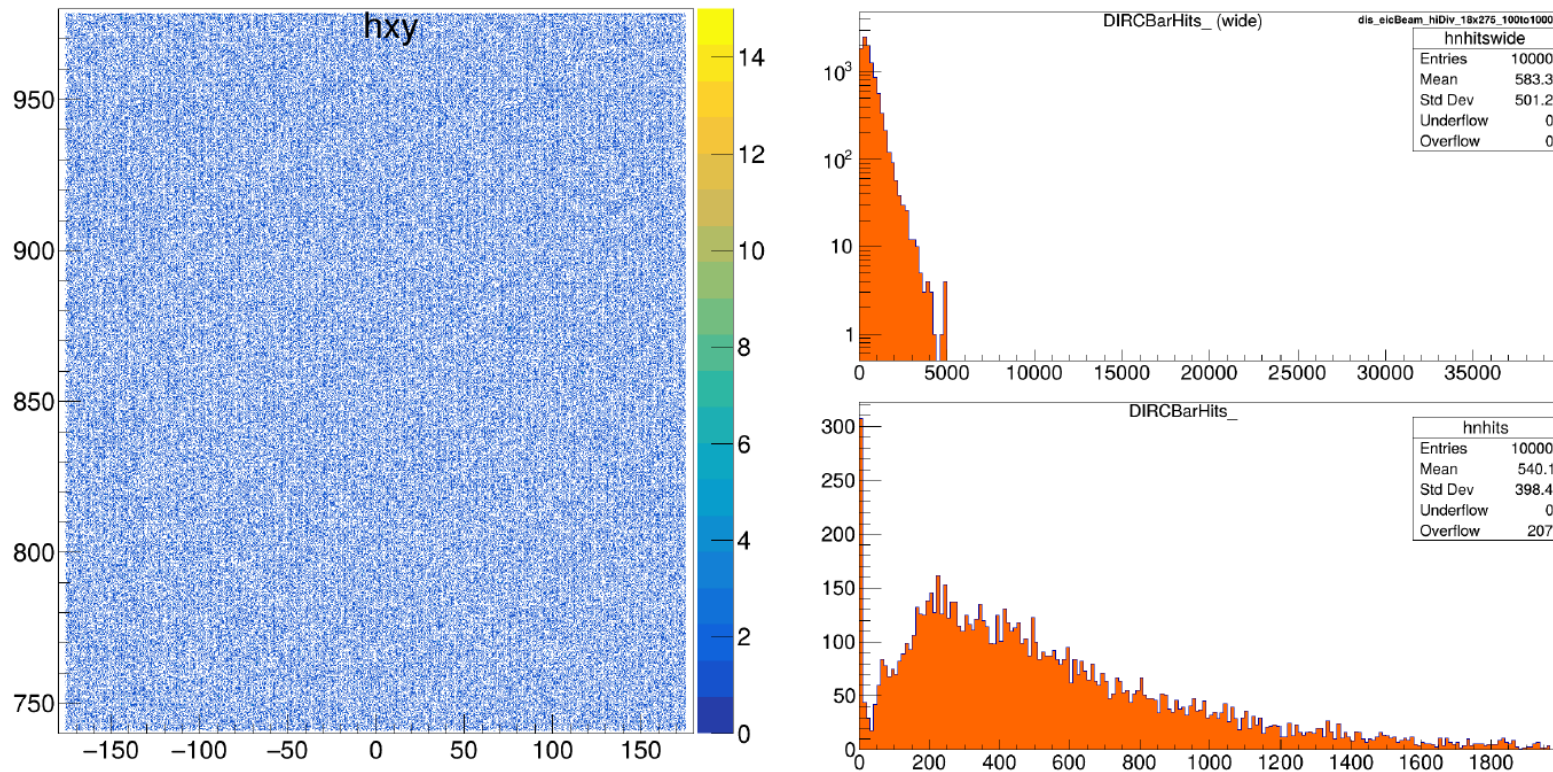
Background Rate

Norm = Rate $\times$ 2 μ s / # sim events



Realistic Hit Distribution

pythia8 DIS, epic, $100 < Q^2 < 1000$



Plots obtained by running npsim over DIS 18x275 hepmc3 datasets produced using pythia8

Hit Rate Estimation (BKG)

❖ Total hit rate: $r = \sum_i R h_i / N$

$R \rightarrow$ Event rate

❖ For instantaneous luminosity (L) of 5.0×10^{33} , 1 fb^{-1} is equivalent to $2 \times 10^5 \text{ sec}$

$h_i \rightarrow$ # hits in i^{th} - cell

$N \rightarrow$ # sim events

Background	Event Rate (kHz)	Total Hit Rate (kHz)	Total Hits / fb^{-1}	Total Hits / fb^{-1} per module
e- Coulomb	0.86	2096.24	4.19×10^{11}	3.49×10^{10}
e- Touschek	0.55	1068.78	2.14×10^{11}	1.78×10^{10}
e- Brem	316.94	30167.22	60.33×10^{11}	50.28×10^{10}
p+ BeamGas	22.5	15583.63	31.17×10^{11}	25.98×10^{10}
Synrad	3324000	0	0	0
Total	-	48915.87	97.83×10^{11}	81.53×10^{10}

The hit rate is overestimated because the simulation does not account for photon detection efficiency (PDE) and the inactive regions between the HRPPDs. Accounting for these effects will reduce the actual hit rate by approximately 50%.

Hit Rate Estimation (SIG)

❖ Total hit rate: $r = \sum_i R h_i / N$

$R \rightarrow$ Event rate

❖ For instantaneous luminosity (L) of 5.0×10^{33} , 1 fb^{-1} is equivalent to $2 \times 10^5 \text{ sec}$

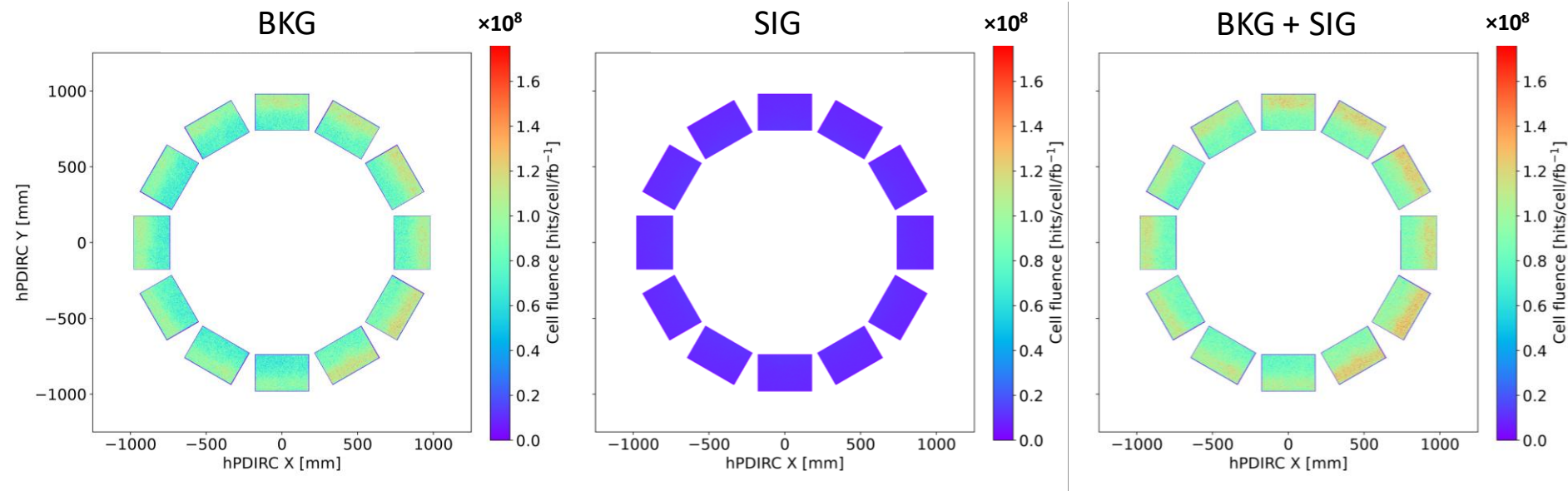
$h_i \rightarrow$ # hits in i^{th} - cell

$N \rightarrow$ # sim events

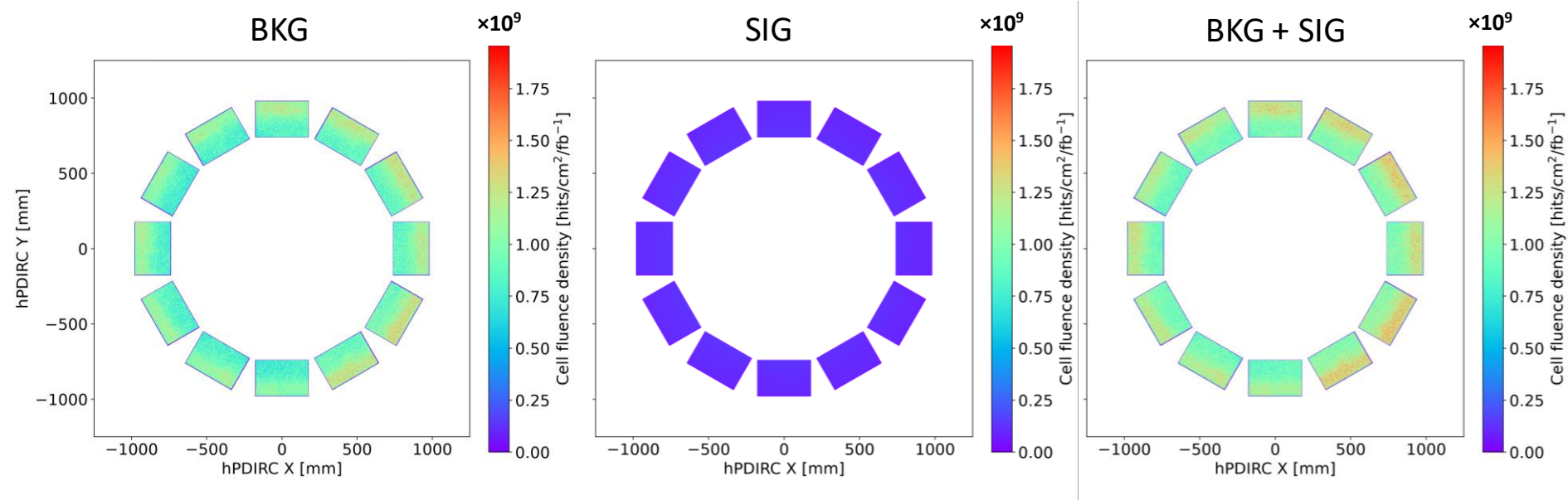
Signal	Event Rate (kHz)	Total Hit Rate (kHz)	Total Hits / fb^{-1}	Total Hits / fb^{-1} per module
SIDIS ep 18x275 $Q^2 = 1 - 10$	3.8543	4916.98	9.83×10^{11}	8.19×10^{10}
SIDIS ep 18x275 $Q^2 = 10 - 100$	0.3270	695.54	1.39×10^{11}	1.16×10^{10}
SIDIS ep 18x275 $Q^2 = 100 - 1000$	0.0131	18.14	3.63×10^9	3.02×10^8
SIDIS ep 18x275 $Q^2 = 1000 - 100000$	0.0002	0.35	7.0×10^7	5.83×10^6
Total	-	5631.01	11.26×10^{11}	9.38×10^{10}
Total (background)	-	48915.87	97.83×10^{11}	81.53×10^{10}

Looking into $Q^2 < 1$ as well; results will be included in a future update

The hit rate is overestimated because the simulation does not account for photon detection efficiency (PDE) and the inactive regions between the HRPPDs. Accounting for these effects will reduce the actual hit rate by approximately 50%.

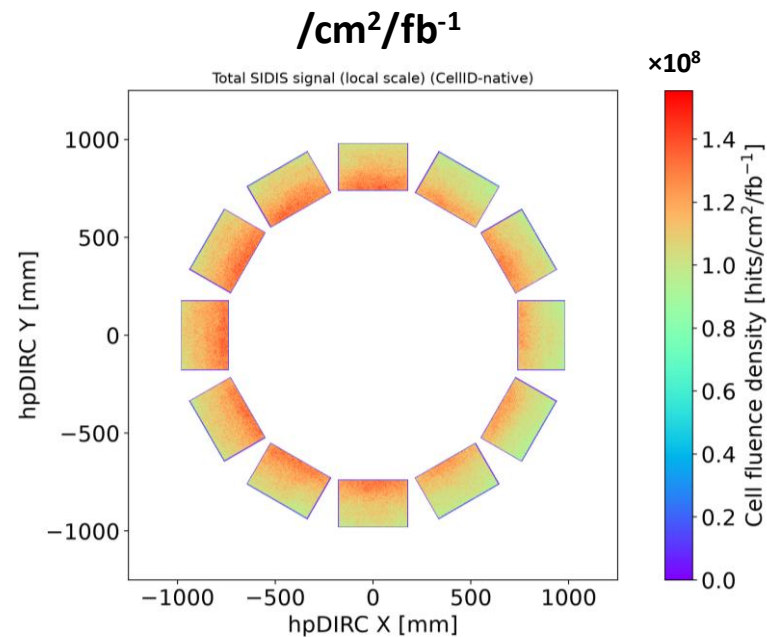
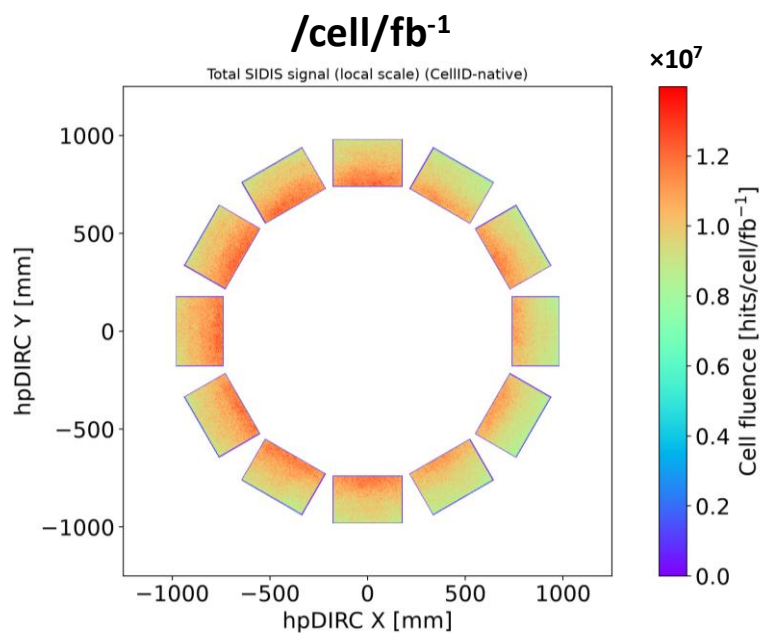


All maps use the same Z-linear scale



All maps use the same Z-linear scale

#Hits (SIG)



Hit Rate Density (BKG+SIG)

$R \rightarrow$ Event rate

$h_i \rightarrow$ # hits in i^{th} - cell

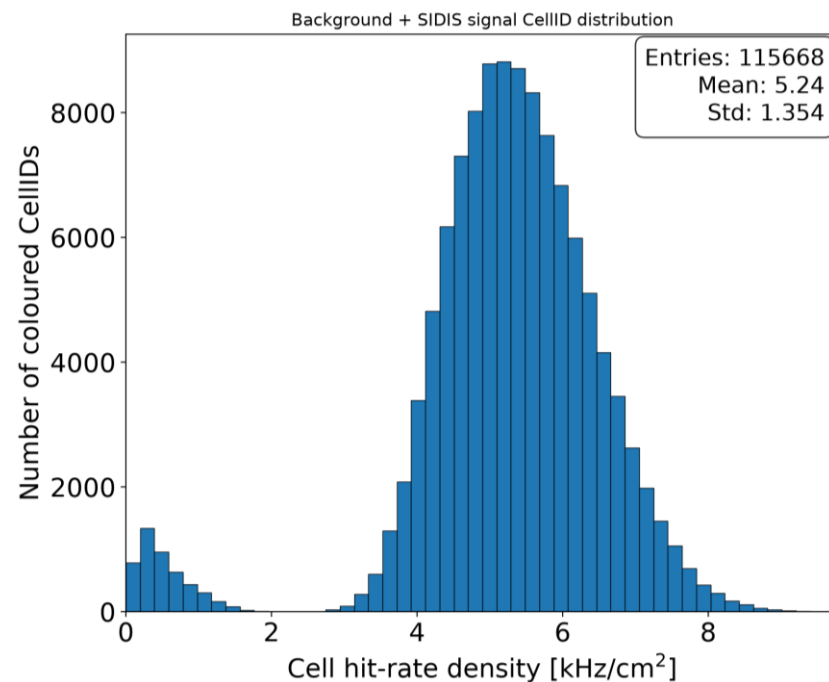
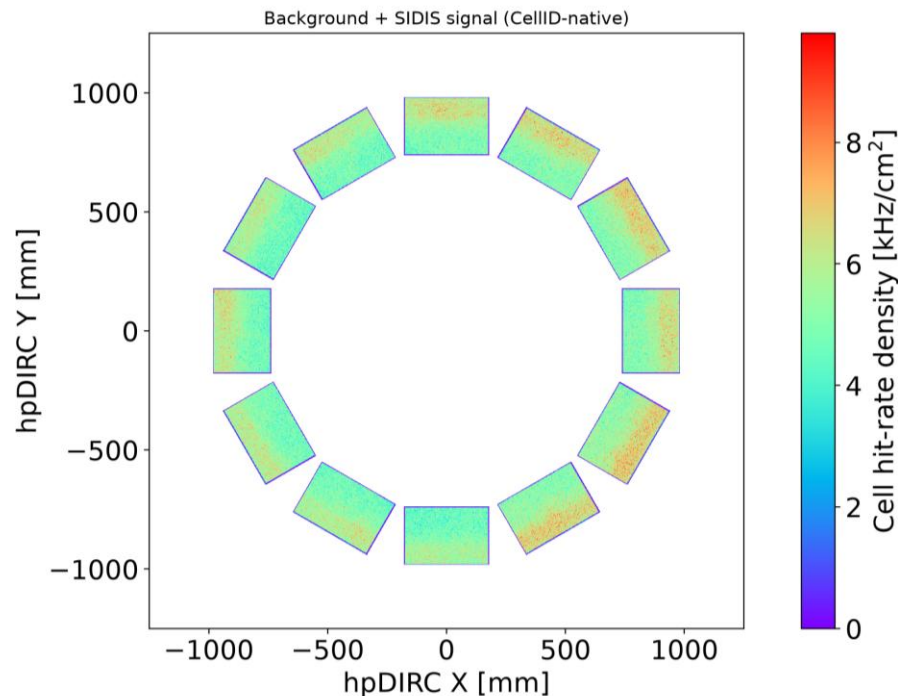
$N \rightarrow$ # sim events

❖ Hit rate: $r_i = R h_i / N$

Hit Rate density: $\rho_i = r_i / 0.09 \text{ kHz/cm}^2$
(for $3 \times 3 \text{ mm}^2$ cells)

18 x 275 GeV

kHz/cm²



Integrated Anode Charge (BKG+SIG)

$r_i^0 \rightarrow$ hit rate density of i^{th} - cell

$t \rightarrow$ time (26 weeks $\times$ 24 h)

$G \rightarrow$ Gain (10^6)

$e \rightarrow$ electronic charge

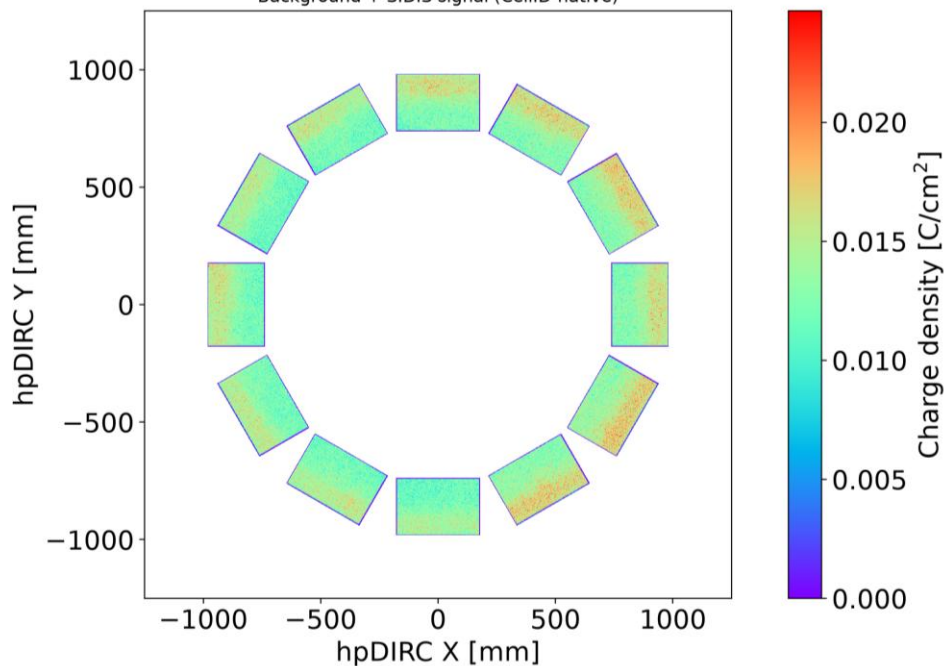
$$\diamond \text{ IAC: } Q/A = \rho_i (\text{kHz/cm}^2) \times 1000 \times t \times G \times e$$

18 x 275 GeV

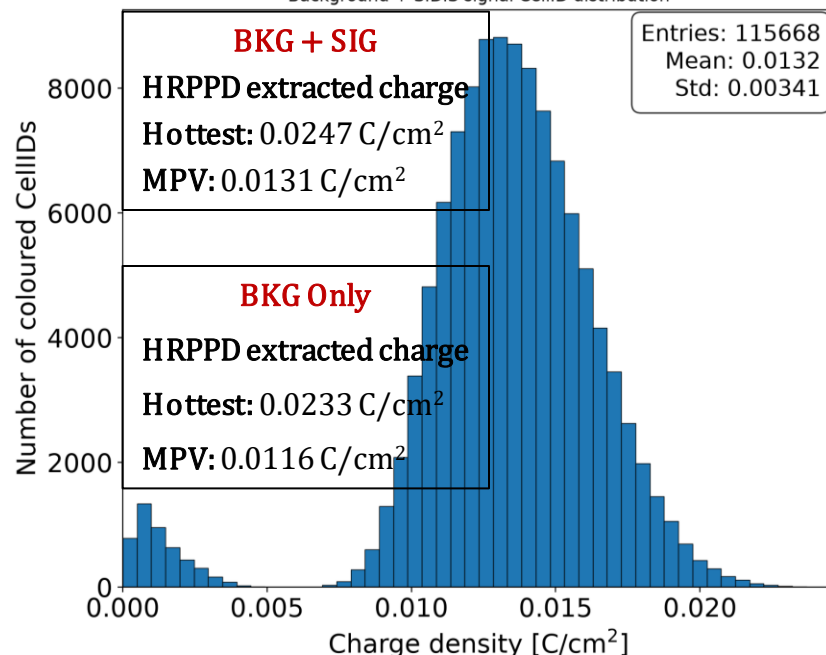
C/cm^2

($\times 0.0025191$)

Background + SIDIS signal (CellID-native)



Background + SIDIS signal CellID distribution



Summary I

- ❖ Background and SIDIS hit rates estimated for 18×275 GeV configuration, assuming instantaneous luminosity of 5.0×10^{33} , 1 fb^{-1} is equivalent to $2 \times 10^5 \text{ sec}$
- ❖ The total background and SIDIS hit rates are approximately **48.9 and 5.63 MHz**, respectively. Note that for SIDIS, $Q^2 = 0-1$ bin has not been included in the calculation
- ❖ The expected fluence is 1.09×10^{13} for combined background and SIDIS hits **per fb^{-1}**
- ❖ The hottest-region **IAC is 0.0247 C/cm^2** with **MPV 0.0131 C/cm^2** for combined background and SIDIS, assuming a 26 weeks $\times$ 24 hr run and HRPPD gain of 10^6
- ❖ Including realistic photon efficiencies and the HRPPD layout is expected to reduce these estimates by about 50%
- ❖ Presently, working on the estimates for the 10×275 GeV configuration

Background Occupancy for 10×275 Configuration

Background Rates

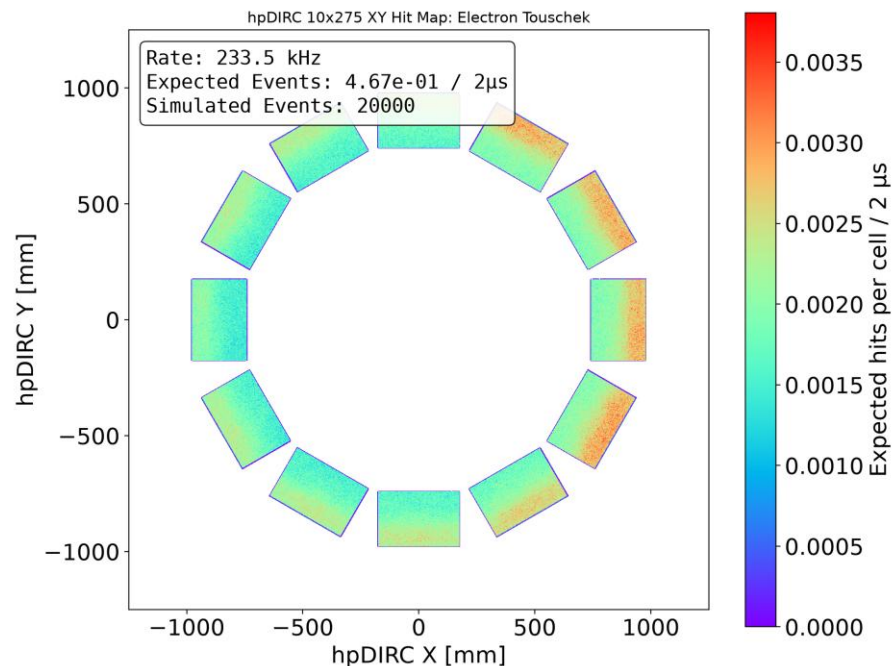
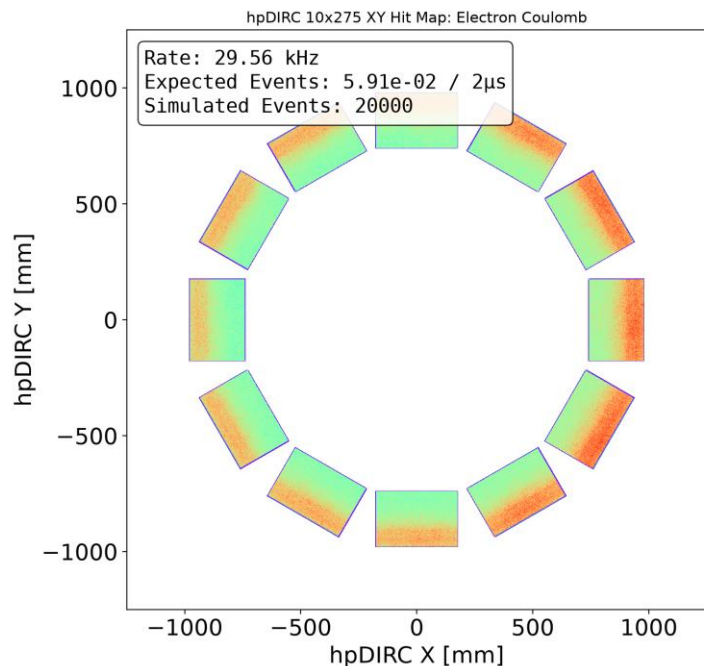
	10 x 275 GeV	18 x 275 GeV
Background	Rate (kHz)	Rate (kHz) (for comparison)
Electron coulomb	29.56	0.86
Electron tousek	233.5	0.55
Electron brem	3177.25	316.94
Proton beam gas	32.6	22.5
Synrad	36.61×10^6	3.32×10^6

Background rates obtained from <https://wiki.bnl.gov/>

Background Hit Pattern

10 x 275 GeV

Z-axis normalized to 2 μ s time: Rate $\times$ 2 μ s / # sim events

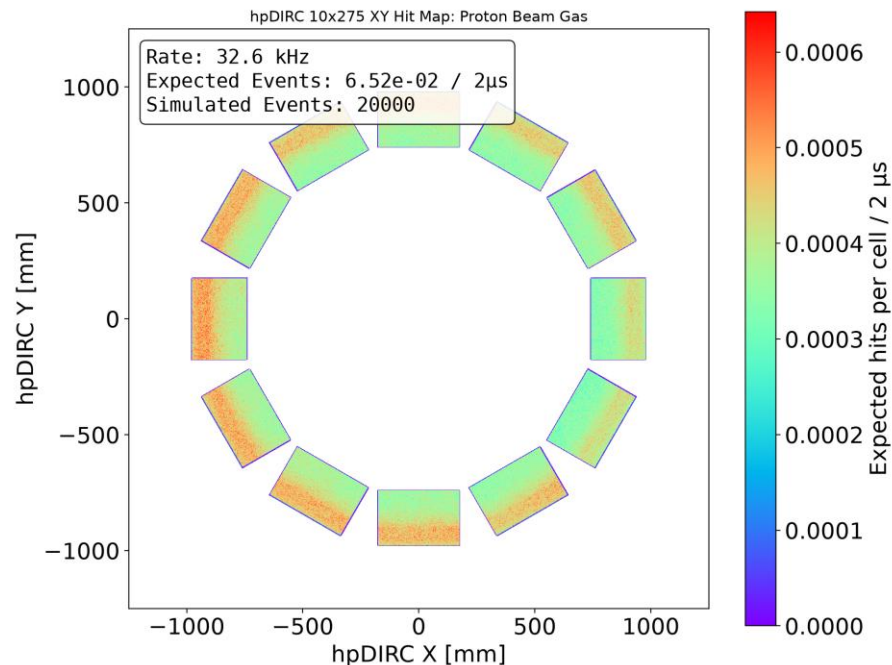
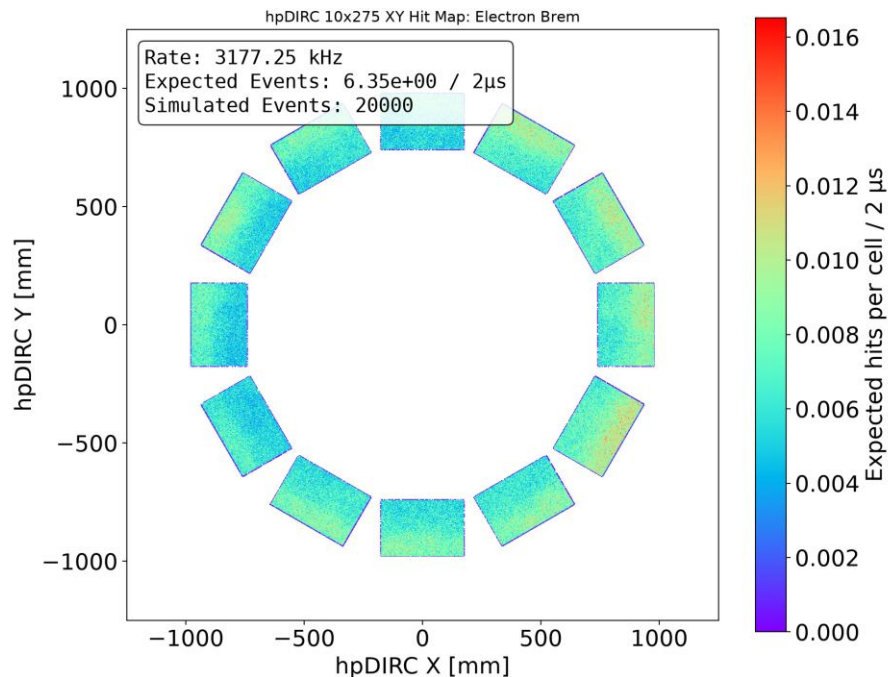


The hit pattern exhibits an **azimuthal asymmetry**, with similar internal variations across modules, having fewer hits at smaller radii.

Background Hit Pattern

10 x 275 GeV

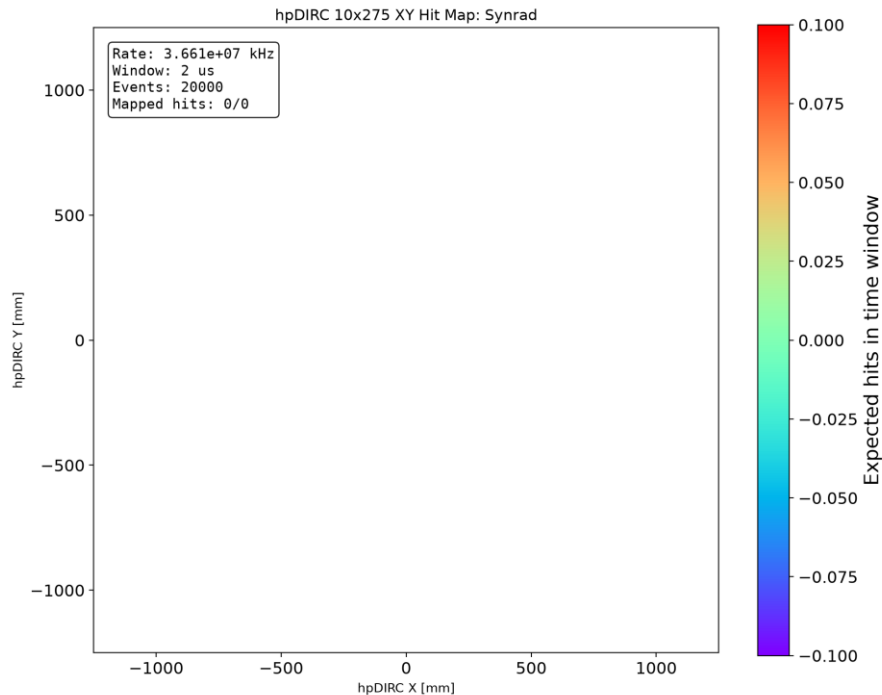
Z-axis normalized to 2 μ s time: Rate $\times$ 2 μ s / # sim events



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Background Hit Distribution

10 x 275 GeV



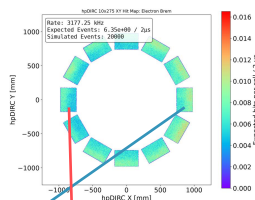
Synchrotron radiation has the highest rate among all backgrounds, but it produces zero hits in hpDIRC.

Note on Hit Position

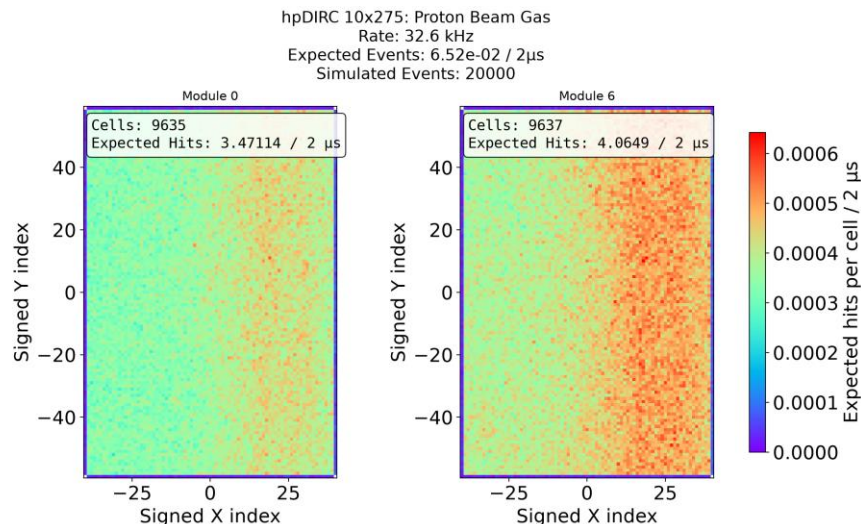
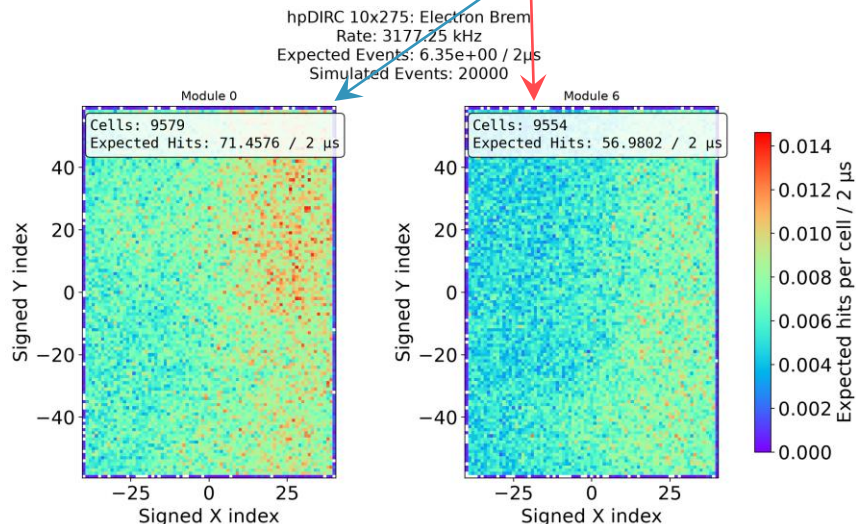
- ❖ Hit positions are not directly available from the epic simulation; only CellIDs are stored
- ❖ The standalone setup provides both CellIDs and their corresponding positions
- ❖ Used the standalone setup to create a mapping from the CellID to their positions for the epic simulation datasets
- ❖ Each pixel in the following 2D plots represents a rotated 3 mm x 3 mm cell, with its position and orientation obtained from the mapping

Background Hit Pattern

10 x 275 GeV



Z-axis normalized to 2 μs time: $\text{Rate} \times 2 \mu\text{s} / \# \text{ sim events}$



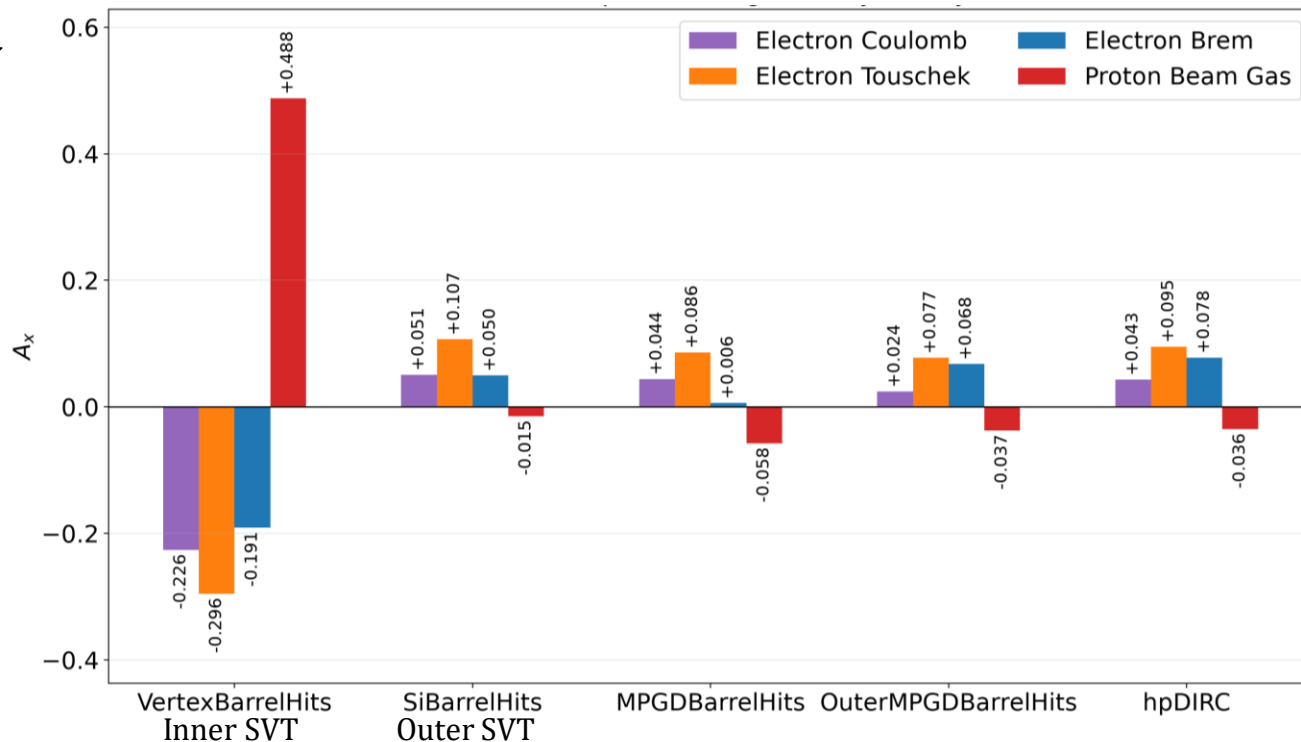
- ❖ To verify that the observed asymmetrical variation is not caused by CellID-to-position conversion, hit distributions were plotted directly using the signed X and Y indices obtained from the CellID

Cross-check with SVT and MPGD Detector Hits

❖ Performed a simple cross-check by calculating left-right (A_x) asymmetries

$$A_x = (N(x>0) - N(x<0)) / (N(x>0) + N(x<0))$$

10 x 275 GeV



SVT → Silicon
Vertex Tracker

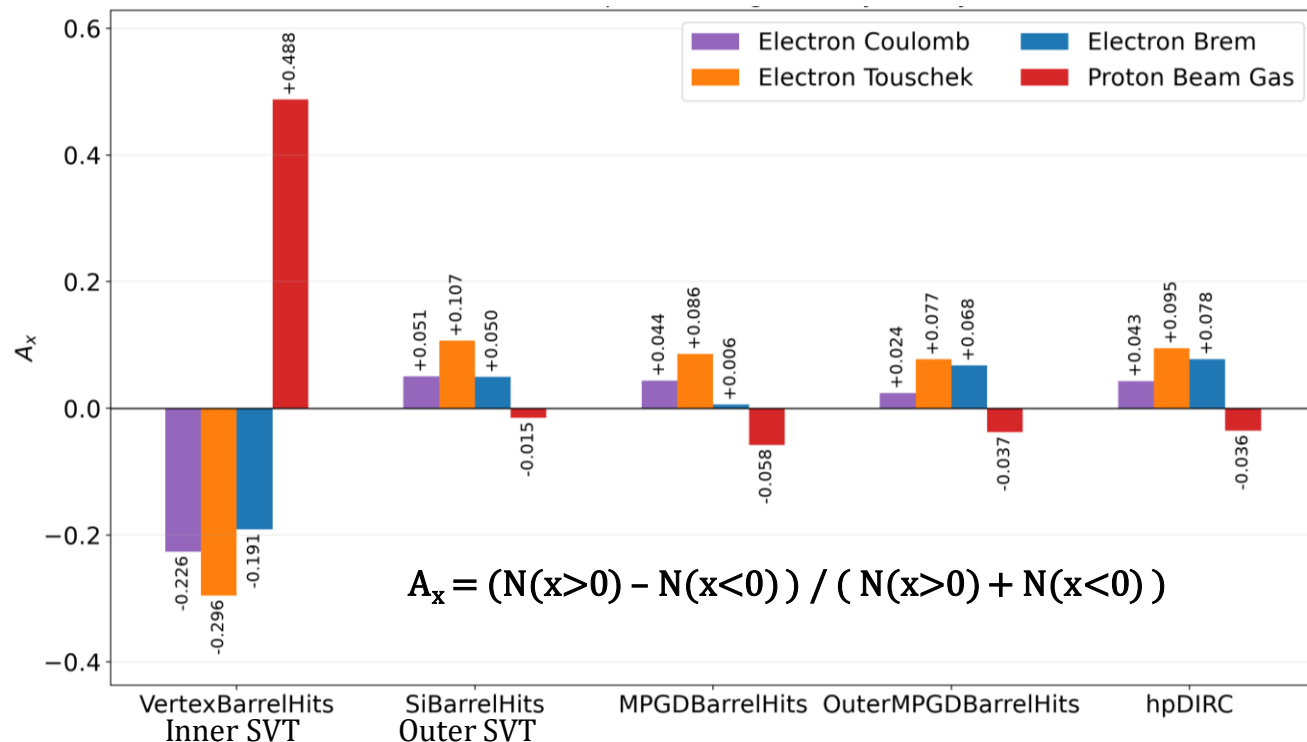
MPGD → Micro-
Pattern Gas Detector

Cross-check with SVT and MPGD Detector Hits

10 x 275 GeV

SVT → Silicon
Vertex Tracker

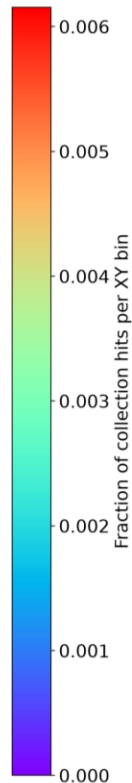
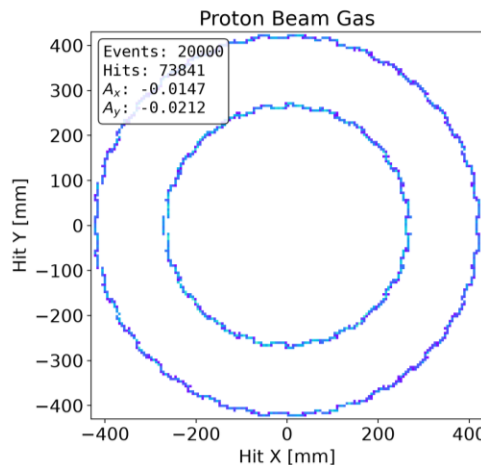
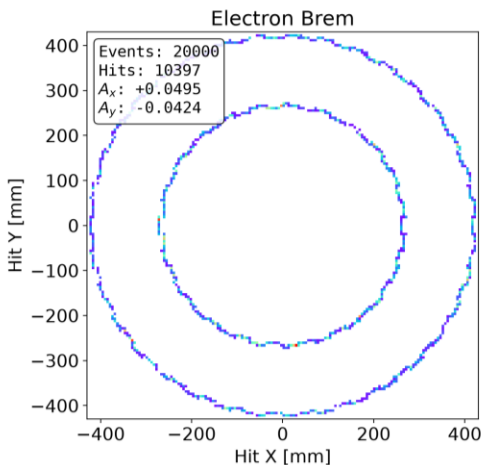
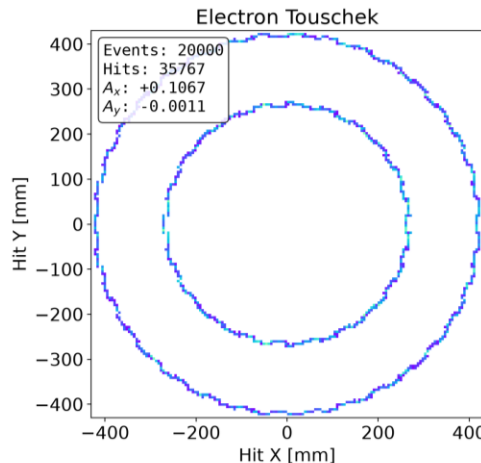
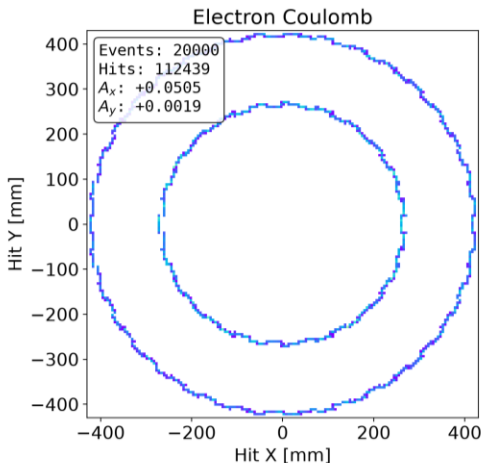
MPGD → Micro-
Pattern Gas Detector



- ❖ The sign of A_x for e^- and p^+ reverses from the inner SVT to the outer SVT layers
- ❖ The same reversed sign persists in the subsequent MPGD tracking layers
- ❖ The sign of A_x is consistent with the asymmetry observed in the hpDIRC

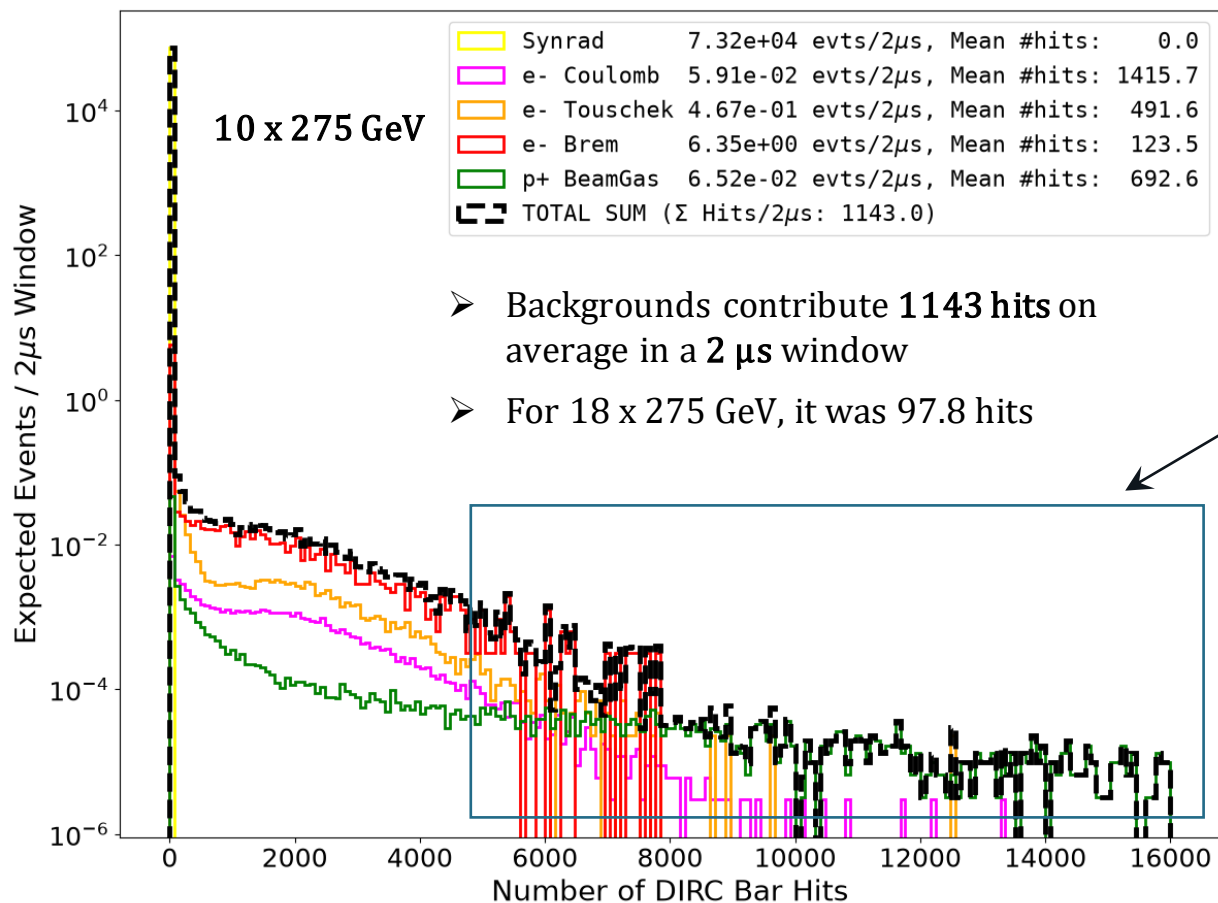
Outer SVT Hit Pattern

- ❖ Asymmetry observed in the outer SVT Hit pattern
- ❖ This confirms that the asymmetry is present in the simulated hit distribution
- ❖ Further study required to identify its physical origin



Background Rate

$$\text{Norm} = \text{Rate} \times 2 \mu\text{s} / \# \text{ sim events}$$



Summary II

- ❖ Background study performed for **10×275 GeV configuration**
- ❖ Including realistic efficiencies and the HRPPD layout is expected to **reduce the estimates by approximately 50%**
- ❖ The hit pattern showed an **azimuthal asymmetry in hpDIRC**
- ❖ It was also observed in tracking detectors, indicating that it is not a mapping artifact; its physical origin remains to be studied
- ❖ **1143 background hits** are expected per 2 μ s window on average for 10×275, compared with 98 for 18×275
- ❖ For signal, SIDIS generation and reconstruction are complete; the 10×275 signal analysis is in progress.

BACKUP

RECO Datasets

❖ Background datasets include:

- `/RECO/26.03.0/epic_craterlake/BACKGROUNDS/SYNRAD/dataproduct_rel_1.0.0/18x275` Synrad
- `/RECO/26.03.0/epic_craterlake/BACKGROUNDS/BEAMGAS/electron/coulomb/EIC_ESR_Xsuite/dataproduct_rel_1.0.1/18x275/10000Ahr/MachineRuntime50s` Electron coulomb
- `/RECO/26.03.0/epic_craterlake/BACKGROUNDS/BEAMGAS/electron/touschek/EIC_ESR_Xsuite/dataproduct_rel_1.0.1/18x275/10000Ahr/MachineRuntime50s` Electron touschek
- `/RECO/26.03.0/epic_craterlake/BACKGROUNDS/BEAMGAS/electron/GETaLM1.0.0-1.1/18GeV` Electron Brem
- `/RECO/26.03.0/epic_craterlake/BACKGROUNDS/BEAMGAS/proton/pythia8.306-1.0/275GeV` Proton BeamGas

❖ Physics signal datasets:

- `/RECO/26.04.1/epic_craterlake/SIDIS/pythia6-eic/1.2.0/ep_noradcor/18x275/q2_1to10`
- `/RECO/26.04.1/epic_craterlake/SIDIS/pythia6-eic/1.2.0/ep_noradcor/18x275/q2_10to100`
- `/RECO/26.04.1/epic_craterlake/SIDIS/pythia6-eic/1.2.0/ep_noradcor/18x275/q2_100to1000`
- `/RECO/26.04.1/epic_craterlake/SIDIS/pythia6-eic/1.2.0/ep_noradcor/18x275/q2_1000to100000`

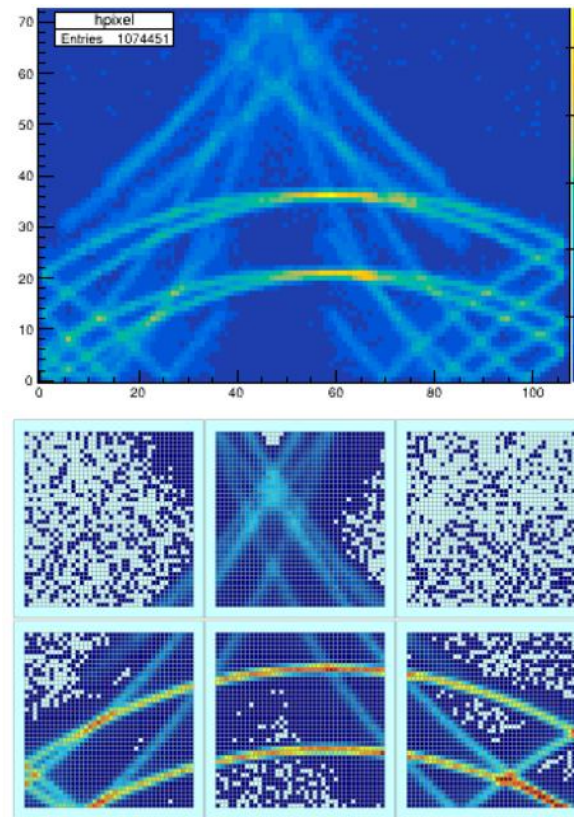
RECO Datasets

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- `/RECO/26.03.0/epic_craterlake/BACKGROUNDS/BEAMGAS/electron/touschek/EIC_ESR_Xsuite/dataproduct_rel_1.0.1/10x275/10000Ahr/MachineRuntime50s` **Electron touschek**
- `/RECO/26.03.0/epic_craterlake/BACKGROUNDS/BEAMGAS/electron/GETaLM1.0.0-1.0/10GeV` **Electron Brem**
- `/RECO/26.03.0/epic_craterlake/BACKGROUNDS/BEAMGAS/proton/pythia8.306-1.0/275GeV` **Proton BeamGas**

Limitations

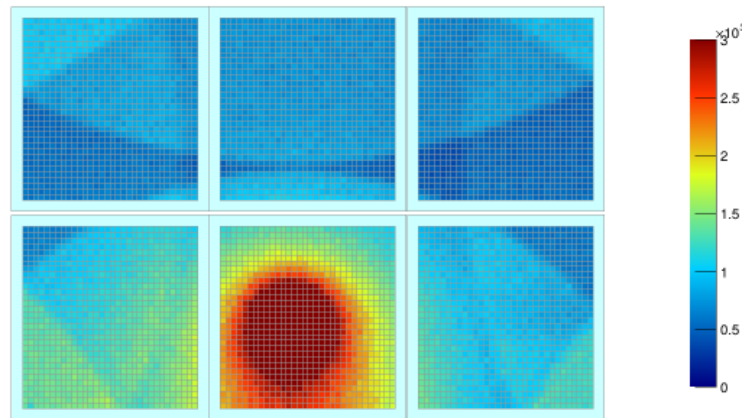
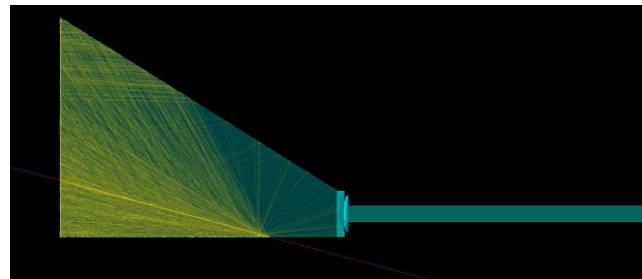
- ❖ Fully pixelated detector plane, no gaps or dead areas
 - Expect occupancy to scale down by $\sim 50\%$ for realistic HRPPD layout and photon detection efficiency
- ❖ Results were produced before the recent software correction for the treatment of photons generated in the prism
 - Current results contain artificial, rare high-multiplicity event anomalies



Results from **standalone simulation**

Limitations

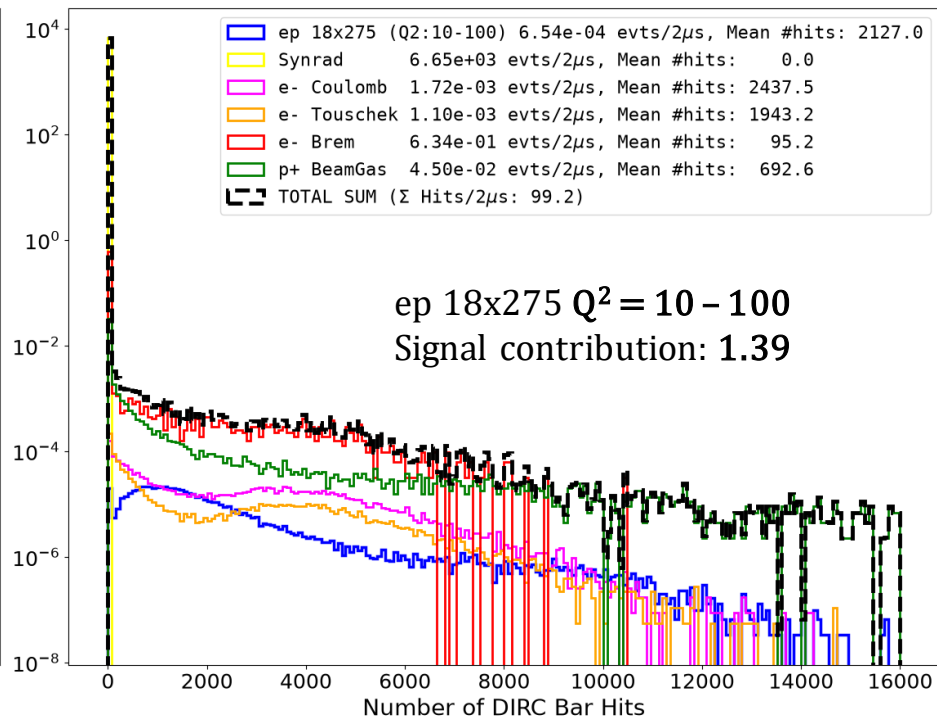
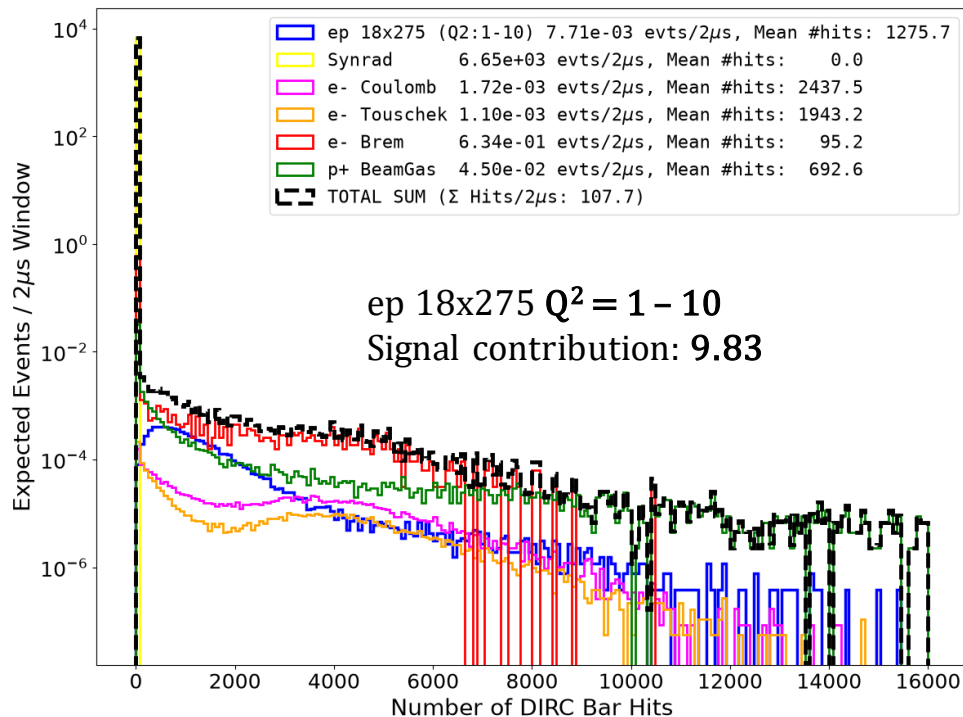
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Results from **standalone simulation**

Signal Rates

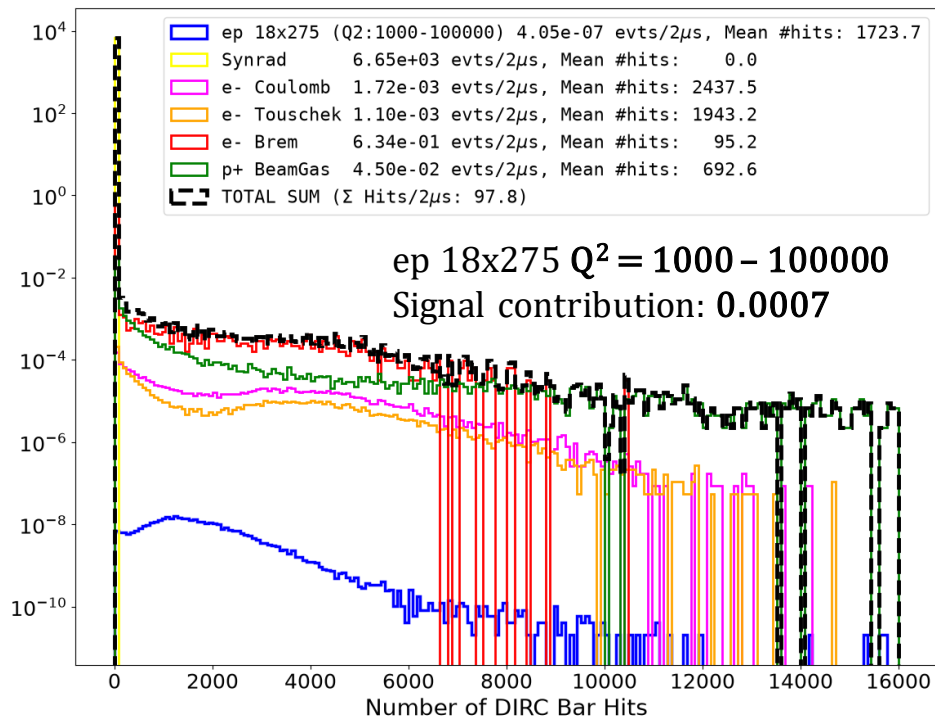
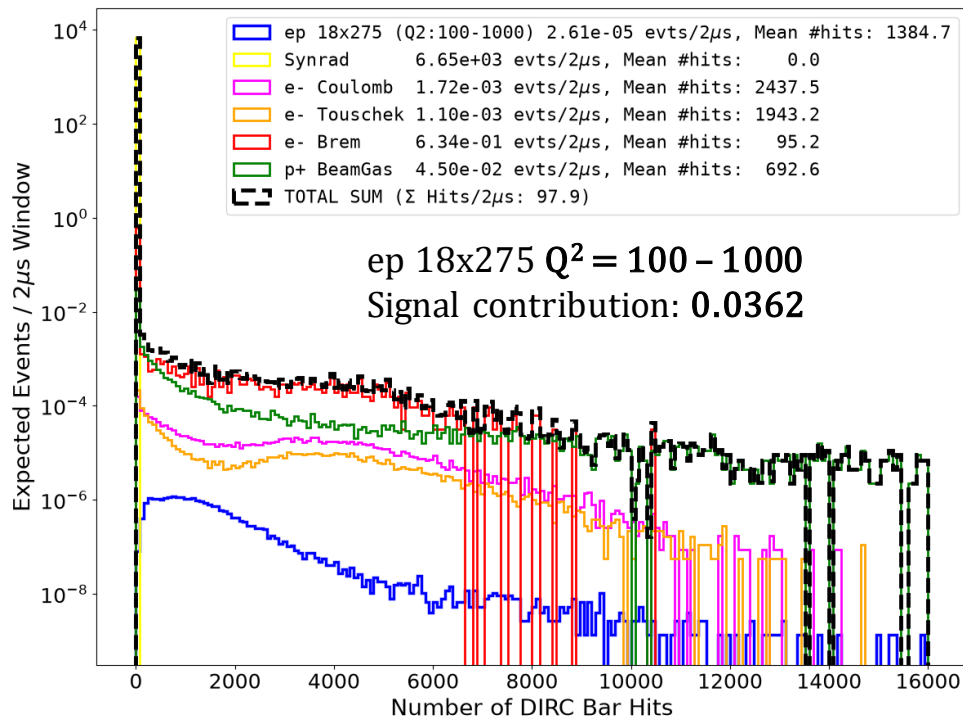
Contribution from backgrounds: **97.8 hits (mean)** in a **2 μ s** window



Norm = Rate $\times$ 2 μ s / # sim events

Signal Rates

Contribution from backgrounds: **97.8 hits** (mean) in a **2 μ s** window



Norm = Rate $\times$ 2 μ s / # sim events

Signal Rates

- ❖ The rate is calculated for an instantaneous luminosity (L) of 5.0×10^{33} as:

$$\text{Rate} = L \times \sigma$$

σ is the **integrated cross-section** of the signal obtained from the EVGEN/hepmc3 files

Signal	Cross-section (pb)	Rate (kHz)
SIDIS ep 18x275 $Q^2 = 1 - 10$	7.70862×10^5	3.8543
SIDIS ep 18x275 $Q^2 = 10 - 100$	6.54077×10^4	0.3270
SIDIS ep 18x275 $Q^2 = 100 - 1000$	2.61440×10^3	0.0131
SIDIS ep 18x275 $Q^2 = 1000 - 100000$	4.04528×10^1	0.0002

Hit Rate Density (BKG)

$R \rightarrow$ Event rate

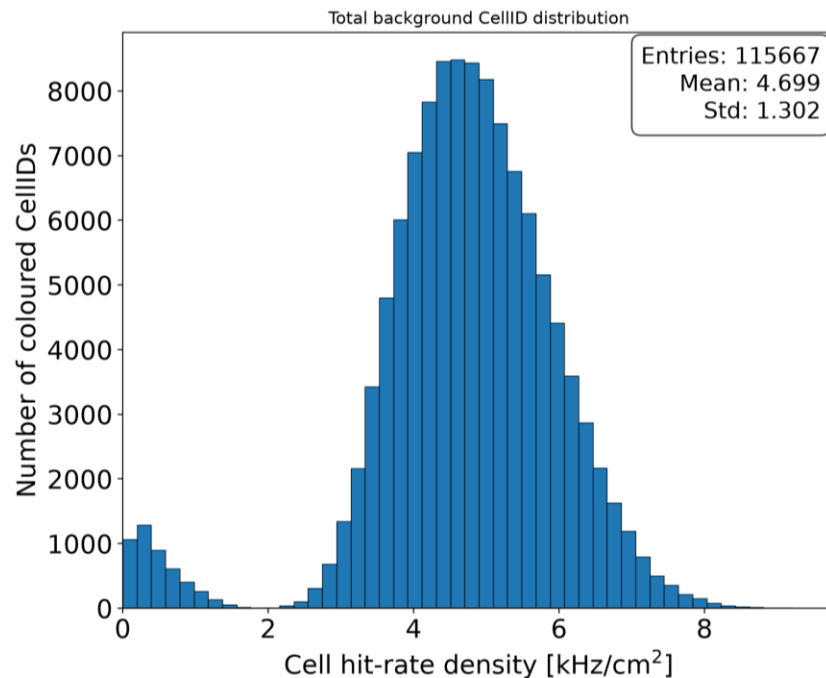
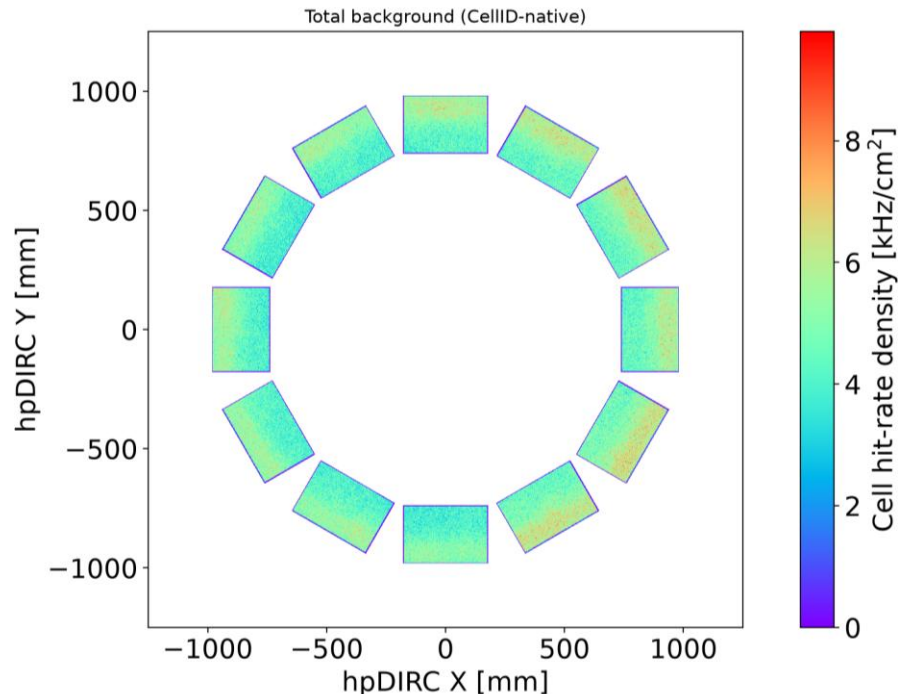
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❖ Hit rate: $r_i = R h_i / N$

Hit Rate density: $\rho_i = r_i / 0.09 \text{ kHz/cm}^2$
(for $3 \times 3 \text{ mm}^2$ cells)

kHz/cm²



Integrated Anode Charge (BKG)

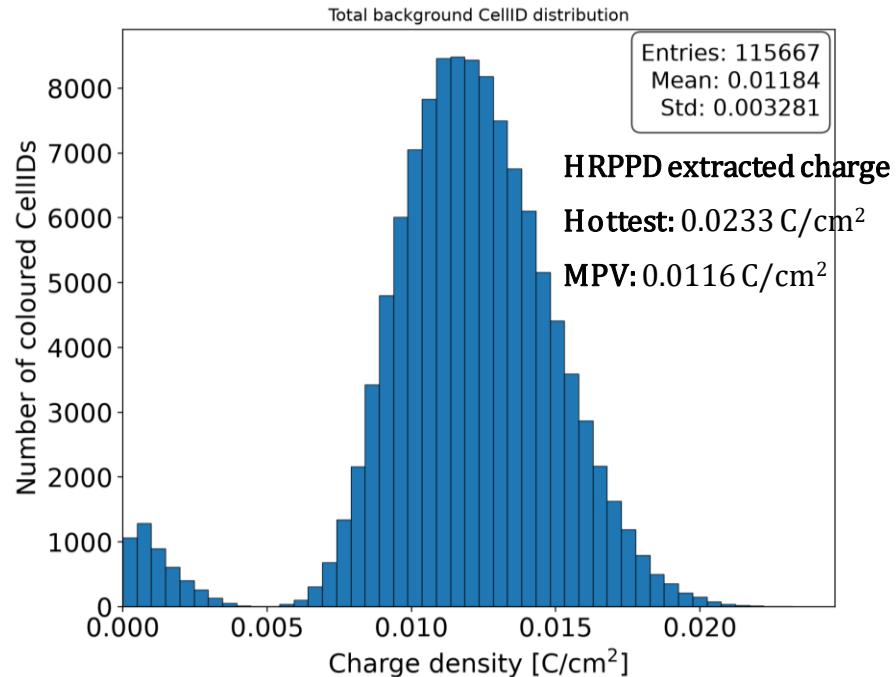
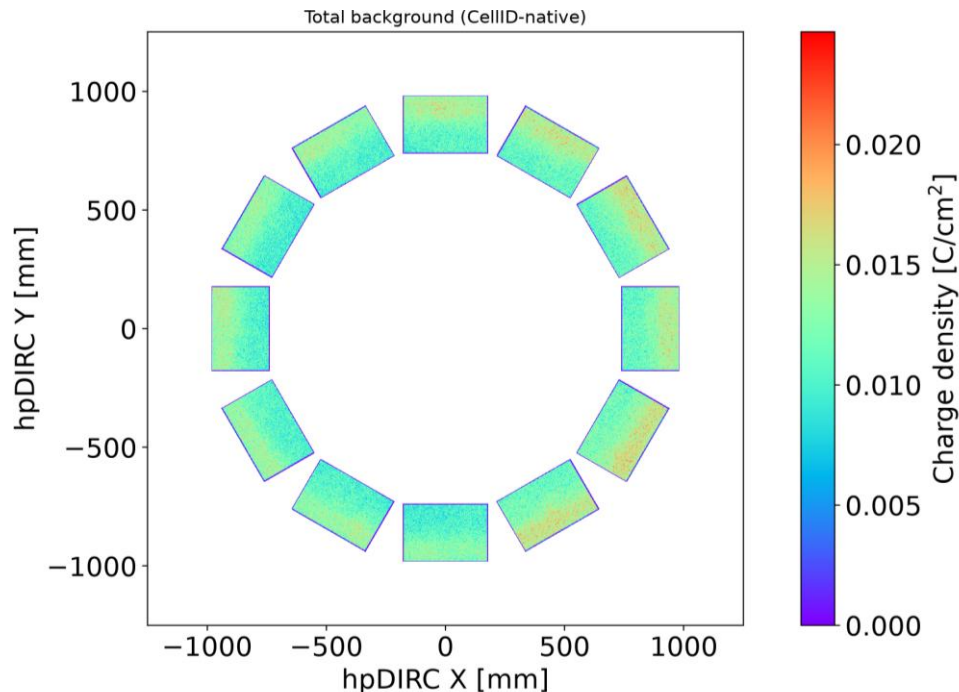
❖ IAC: $Q/A = \rho_i (\text{kHz/cm}^2) \times 1000 \times t \times G \times e$
 $(\times 0.0025191)$

$r_i^0 \rightarrow$ hit rate density of i^{th} - cell

$t \rightarrow$ time (26 weeks $\times$ 24 h)

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Hit Rate Density (SIG)

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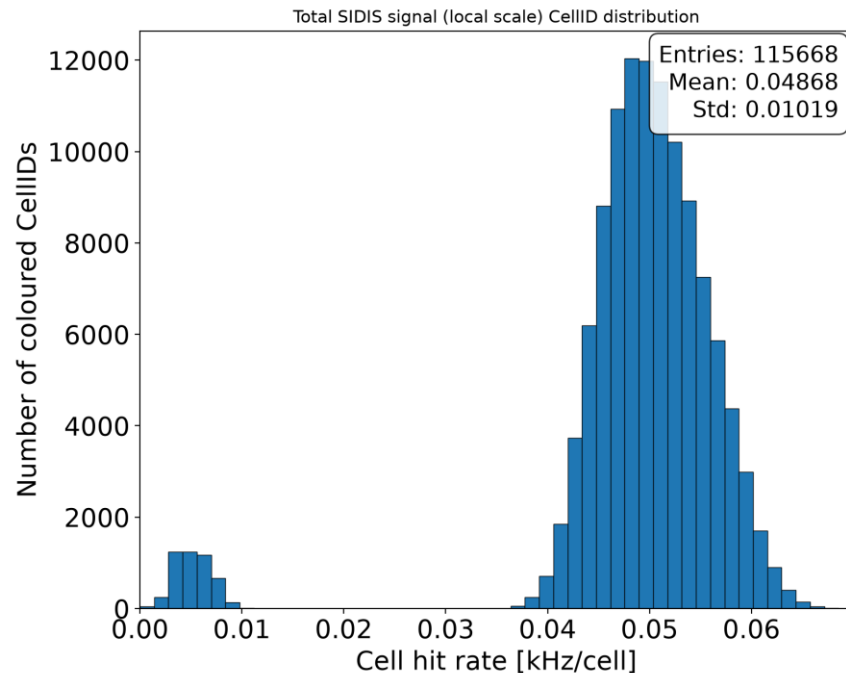
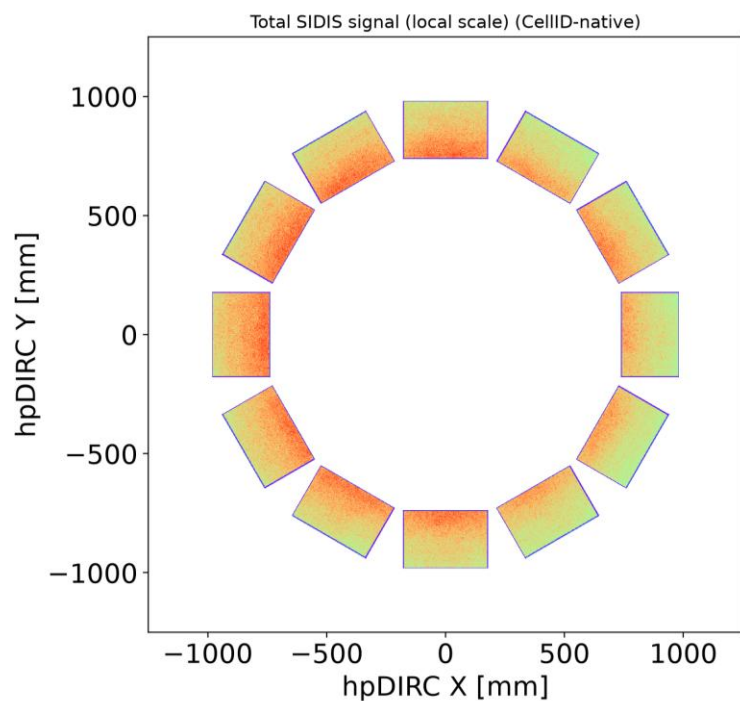
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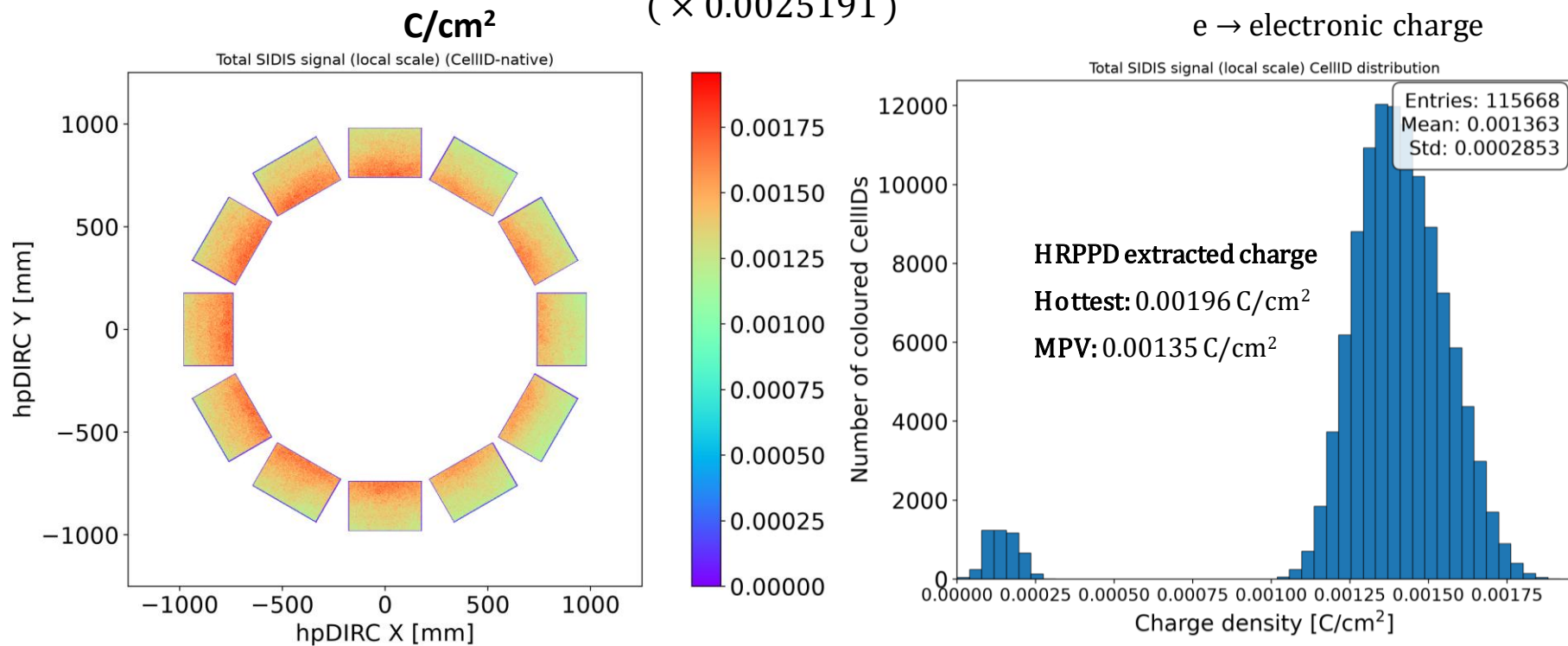
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Fitting and Transformation Map

$$P(i_x, i_y) = O + i_x e_x + i_y e_y$$

$$\theta_m = 30^\circ \times m$$

$$e_x = 3(\cos \theta_m, \sin \theta_m)$$

$$e_y = 3(-\sin \theta_m, \cos \theta_m)$$

$$O = \bar{P} - \bar{i}_x e_x - \bar{i}_y e_y$$

Residual being minimized

$$r_k(O) = P_k - O - i_{x,k} e_x - i_{y,k} e_y$$

$$\chi^2(O) = \sum_{k=1}^N \| r_k(O) \|^2$$

(i_x, i_y)

signed local CellID indices, unitless

(e_x, e_y)

fixed global basis vectors, mm per index

$P_k = (X_k, Y_k)$

GEANT4 mean position, mm

$O = (O_x, O_y)$

fitted module origin, mm

$$M = [e_x \ e_y] = \begin{bmatrix} e_{x,x} & e_{y,x} \\ e_{x,y} & e_{y,y} \end{bmatrix}$$

HRPPD Requirements

High-rate tolerance

Main concerns: gain stability and photocathode ageing

Hit rate estimate based on simulation, 18x275 GeV cross sections,
assume instantaneous luminosity 5×10^{33} , 1fb^{-1} equiv. to 2×10^5 sec

- Backgrounds dominated by e- Brem and p+ BeamGas
- The sensor gain may drop for large rates of detected photons
 - Expect **10 kHz/cm² average hit rate** (90% from background)
- The sensor lifetime may be reduced due to photocathode ageing
 - Expect **14 mC/cm²/year** average integrated anode charge (IAC) at 10^6 gain (90% from backgrounds)
- Both values are quite modest and similar to pFRICH

hpDIRC requirements:

- **gain stable up to at least 20 kHz/cm²**
- **no significant QE loss up to 0.1 C/cm² per year IAC at 10^6 gain**

HRPPD performance and specifications meet requirement

Comparison with pfRICH

```
hpDIRC (18x275, combined) versus pfRICH (10x275, reference) (1.57248e+07 s, gain 1e+06):
```

Quantity	hpDIRC	pfRICH
Total background hit rate [hits/s]	4.89159e+07	8e+07
Total signal hit rate [hits/s]	5.63106e+06	1e+07
Total combined hit rate [hits/s]	5.45469e+07	9e+07
Peak rate density [hits/cm ² /s]	9795.08	200000
MPV rate density [hits/cm ² /s]	5191.39	6000
Peak extracted charge [C/cm ²]	0.0246776	0.503878
MPV extracted charge [C/cm ²]	0.0130791	0.0151163