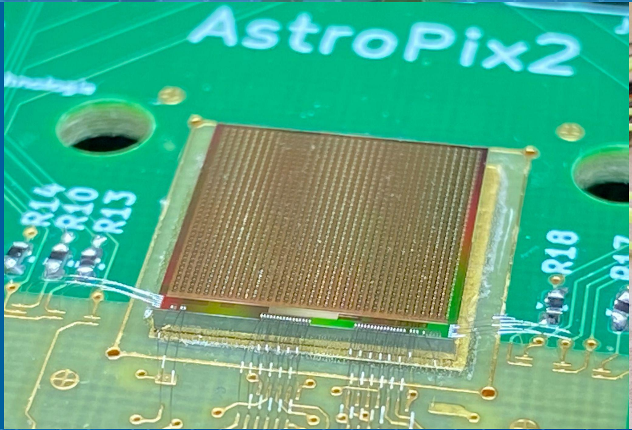
ePIC Barrel ECal Review, March 13-14, 2023

The Imaging Calorimeter for ePIC
Answers to Committee



ePIC

Question 1: Could you please confirm that the integration time of Astropix is 10 microseconds?

- The integration time is **6μs for each 500 μm x 500 μm** pixel separately and does ***not* impact neighboring pixels or sensors**. Once data from a pixel is read out, it is pushed to the on-sensor buffer and then to the data stream.

- Our system has extremely high granularity: We have ~ 88M pixels per layer in the calorimeter (total of ~ 528M pixels). The upper limit of the hit rate* is < 3 x 10^7 Hz over the entire detector. This corresponds to an average hit rate of < 0.06 Hz/pixel. The rate of a single pixel being hit twice within the 6μs window is < 1.9 x 10^{-8} Hz, which translates to < 10 Hz when considering the entire detector. This corresponds to a **drop rate for the entire detector below 1 out of every 2.9M hits.** In high-rate areas it may be up to 1 out of 1M.

- As a point of comparison, the new ATLAS ITk tracker will drop < ~ 1/10k hits due to similar effects. Due to our substantially lower drop rate, we have many orders of magnitude safety margin without any drop in performance.

- The integration time for the Astropix pixels is very typical for MAPS sensors, including the ITS3-based MAPS tracker in ePIC. The integration time per pixel **does not meaningfully impact our capability to perform a streaming readout model** with near-100% lifetime.

* from a preliminary background study *without* appropriate detector thresholds (see backup slide). The actual rate is expected to be much lower.

Question 2: Could you please follow up on the maximum throughput of the chip-to-chip daisy chain to ensure sufficient safety factors to trigger-less readout 0.1-m^2 of Astropix sensors (as much of the background study is still ongoing)?

The chip-to-chip daisy chain only spans a single silicon stave. One silicon stave is 108 Astropix sensors daisy-chained together, which measures 2 cm x 216 cm (one chip x half calorimeter length). The entire detector has a total of ~ 1656 silicon staves.

- We can combine multiple daisy chains into a single aggregator, with the number driven by the data rate.
- It takes ~ 1 μs to push a hit from the AstroPix sensor** onto the aggregator; **for a 108-chip stave the maximum data throughput is ~ 10 Gb/s,** which corresponds to a maximum hit throughput of ~ 100 MHz.
    - 0.1 m^2 corresponds to about two silicon staves with separate daisy chains; the combined throughput limit would be ~ 20 Gb/s.
- Each AstroPix sensor has a large buffer of > 1000 hits to deal with large bursts of hits.

To put this into context:

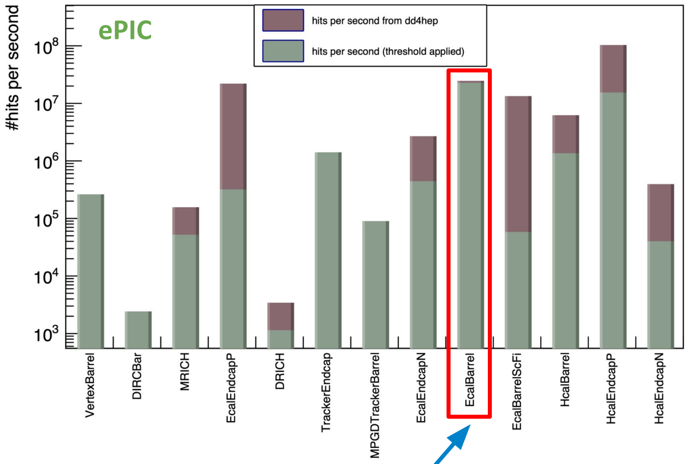
- The expected hit rate for all imaging layers together is well below < 3 x 10^7 Hz, as derived on the following slides. This translates to a maximum hit rate per daisy chain < 36 kHz, **giving a safety factor > 2500**.
- The largest hit multiplicity per stave is seen for high-Q^2 DIS events, which is still only < 25 hits per stave***. Our setup is capable of dealing with much greater multiplicities.

** Single hit size is 96 bit

*** As observed from Pythia8 NC Q^2 > 1000 GeV^2

Upper limit on the Detector Rates

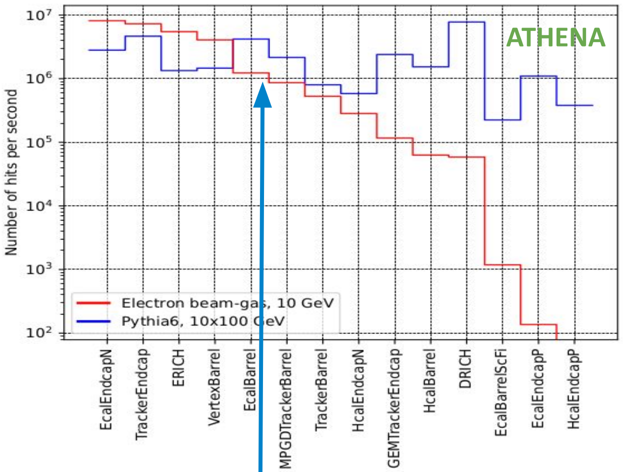
Hadron beam background



ePIC	EcalBarrel	2.26E+07

Source: ePIC Beam Backgrounds (LINK)

Electron beam background and **NC DIS** rates



Currently only ATHENA numbers available

- Pythia6 $Q^2 > 10^{-9}$ GeV^2: **5 x 10^6 hits/s**
- Electron beam: **2 x 10^6 hits/s**
- Synchrotron Radiation: **Small**

Source: ATHENA Beam Backgrounds (LINK)

- 5 x 10^6 hits/s + 2 x 10^6 hits/s + 2.26 x 10^7 hits/s = **2.96 x 10^7 hits/s**
- 2.96 x 10^7 hits/s * 96 bits = **2.84 Gbps**

Upper limits on rates due to incorrect threshold subtraction: see the next slide

Thresholds taken in the rate studies

Hits Rate and Threshold

	readout	no. hits per	Threshold	after threshold
VertexBarrel	0.010mm*0.010mm	2.27E+05	0.4keV	2.27E+05
DIRCBar	3.0mm*3.0mm	4.40E+06		4.4E+06
ERICH	3.2mm*3.2mm	4.81E+05	divided by 3	1.60E+05
EcalEndcapP	1 fiber (20.5mm*20.5mm)	3.58E+07	5 MeV	7.34E+05
DRICH	3.2mm*3.2mm	8.05E+06	divided by 3	2.68E+06
TrackerBarrel	0.010mm*0.010mm	1.33E+05	0.4 keV	1.33E+05
TrackerEndcap	0.010mm*0.010mm	1.61E+06	0.4 keV	1.61E+06
MPGDTrackerBarrel	0.52mm*0.52mm	5.75E+05	0.2 keV	5.31E+05
GEMTrackerEndcap	0.17mm*0.87mm	1.14E+06	0.2 keV	1.03E+06
EcalEndcapN	1 fiber (20.5mm*20.5mm)	9.43E+05	2.5 MeV	8.47E+04
EcalBarrel	0.5mm*0.5mm	8.02E+05	0.4 keV	[illegible].71E+05
B0Preshower		4.13E+04		4.13E+04
EcalBarrelScFi	1 fiber	2.06E+07	2.5 MeV	8.19E+04
HcalBarrel	100.0mm*100.0mm	6.63E+06	0.1 MeV	1.29E+06
HcalEndcapP	100.0mm*100.0mm	3.36E+07	300 MeV	2.36E+05
HcalEndcapN	100.0mm*100.0mm	9.34E+04	0.1 MeV	2.04E+04
B0Tracker		1.86E+05		1.86E+05
ForwardOffMTracker		2.11E+03		2.11E+03
ffiZDCSi		4.36E+03		4.36E+03
ffiZDCWSciFi		2.03E+05		2.03E+05
ffiZDCSiPb		1.91E+05		1.91E+05
ForwardRomanPot		1.35E+05		1.35E+05
ffiZDCScint		5.03E+03		5.03E+03

For EPIC, I used 0.1MeV (single layer) threshlold for Hcal, a similar threshold like Athena case may need to be studied;

- **0.4 keV** threshold taken in the studies
- This is way too low
- Our zero-suppression: **4 x 5 keV = 20 keV**
- **Because of this the numbers on the previous slide are an upper limit**
- The true background rate is likely one or more orders of magnitude smaller (collaboration-wide study in progress).

Source: Zhengqiao Zhang, BNL, Proton beam gas background for EPIC (LINK)