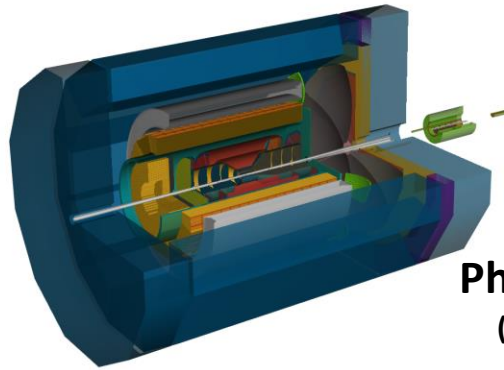
SiPMT readout for RICH
Does ECCE has same issue as ATHENA

Detector 1 DAQ WG
June 23rd 2022
Jeff Landgraf (BNL), Alexandre Camsonne (JLAB)

ATHENA Streaming Readout Architecture



Data
Configuration Control
Clock Trigger
Power

O(2.5 Tbps) Zero-supression O(500 Gbps) Clustering / Detector correlations O(150 Gbps)

Detector
Sensor
FEB (Front End Board)
AGG (Aggregation)
FEP (Front End Processor)
DAQ (Data Acquisition)

MAPS
MGPDs
Photosensor (SiPMT,MCP)
LGAD

ASIC
ASIC Or FADC
ASIC

Fiber
Fiber
Fiber

FEB
FEB
FEB

AGG
AGG
AGG

L ~ 100 m fiber

FELIX

Switch / Server / Readout
Switch / Server: Processing
Switch / Server: Buffer

Global timing, busy & sync
Beam collision clock input

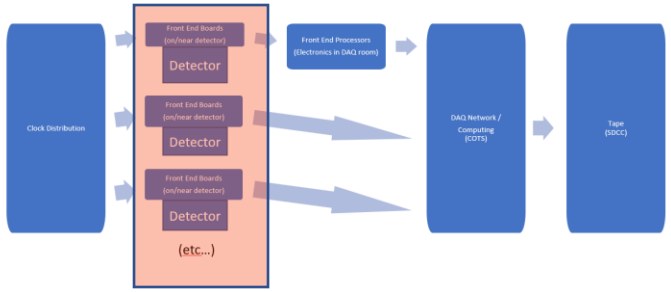
Storage
Monitoring

LVDS ~ 5m
Analog ~ 20m

Power Supply System (HV, LV, Bias)

Cooling Systems

Front End Boards (FEB)



- The collider performance:
  - ~500KHz of collisions
  - ~60-100Gbps zero suppressed data
  - ~15 KB/event
  - ~100 bytes/bunch crossing
- We have an enormous number of channels but the Silicon MAPS readouts test the relevance of the concept of channel.
- Challenging data compression scheme
  - Noise reduction
  - Zero suppression
  - Background elimination

Detector	Readout Technology	Channel Count
Silicon Tracking	Si MAPS	37B
GEM/MMG Layer	GEM	217K
Cylindrical MPGD *	GEM	60M
HP-DIRC	MAP/MT	100-330k
ECAL	SiPM	1.7K
HCAL	SiPM	24K
HCAL imaging	Si MAPS	480M
dRICH	PMT/SiPM	350K
mRICH	PMT/SiPM	330K
B0	Si MAPS	32M + 320K
Off-Momentum	AC-LGAD (eRD24)	750K
Roman Pots	AC-LGAD (eRD24)	500K
ZDC	LGAD + ASIC eRD27	225+366
TOF	AC-LGAD	15M

Some Obvious Points

Detector	Channels
RICH	625k
Calorimeters	72k
Imaging Calorimeter (MAPS)	619M
Tracking MAPS	60B
Tracking MPGDs	144k
Far Forward (MAPS)	400M
Far Forward	1100k
Far Backward	4k
TOF	332k
Total MAPS	61B
Total Channels	2.3M

- Assume O(100Gbps) Bandwidth to tape
  - Hit Size ~ 64 bits (24 bits time, 24 bits position, 12 bits, 4 status)
  - 1 Hit / bunch crossing = 6.4Gbps (~5% of bandwidth assumed)
  - At 500Khz, average event size ~25KB (~3.1K hits / event)
- 2.3M channels + 60k MAPS sensors
  - In flux, but currently ~4.5k Fiber reading into ~120 FELIX boards
- Assume O(3.5Tbps) Bandwidth to DAQ computers
  - 2.3M channels + 60k MAPS sensors
    - ~4.5k Fiber reading into ~120 FELIX boards
    - ~ < 1Gbps / fiber (fiber capacity ~6 Gbps)
    - ~ < 25Gbps / FELIX (FELIX bandwidth ~100 Gbps)
- We will need to pay a lot of attention to noisy channels, flaky fibers, and any other potential noise sources

Side by side ATHENA/ECCE

Detector	Readout Technology	Channel Count
Silicon Tracking	Si MAPS	37B
GEM/MMG Layer	GEM	217K
Cylindrical MPGD *	GEM	60M
HP-DIRC	MAP/MT	100-330k
ECAL	SiPM	1.7K
HCAL	SiPM	24K
ECAL imaging	Si MAPS	480M
dRICH	PMT/SiPM	350K
mRICH	PMT/SiPM	330K
B0	Si MAPS	32M + 320K
Off-Momentum	AC-LGAD (eRD24)	750K
Roman Pots	AC-LGAD (eRD24)	500K
ZDC	LGAD + ASIC eRD27	225+366
TOF	AC-LGAD	15M

PID WBS Name	Detector	Channels
Barrel PID	hpDIRC	69,632
	TOF	8,600,000
Electron Endcap	mRICH	65,536
	TOF	920,000
Hadron Endcap	dRICH	5,376
	TOF	1,840,000
Far-Forward Detectors	Roman Pots	524,288
	B0 Detector	2.6M
	Off-Momentum Detectors	1.8M
Far-Backward Detectors	Low-Q^2 Tagger	4.6M
	Luminosity Monitor	268,441

Side by side ATHENA/ECCE

Detector	Readout Technology	Channel Count
Silicon Tracking	Si MAPS	37B
GEM/MMG Layer	GEM	217K
Cylindrical MPGD *	GEM	60M
HP-DIRC	MAP/MT	100-330k
ECAL	SiPM	1.7K
HCAL	SiPM	24K
ECAL imaging	Si MAPS	480M
dRICH	PMT/SiPM	350K
mRICH	PMT/SiPM	330K
B0	Si MAPS	32M + 320K
Off-Momentum	AC-LGAD (eRD24)	750K
Roman Pots	AC-LGAD (eRD24)	500K
ZDC	LGAD + ASIC eRD27	225+366
TOF	AC-LGAD	15M

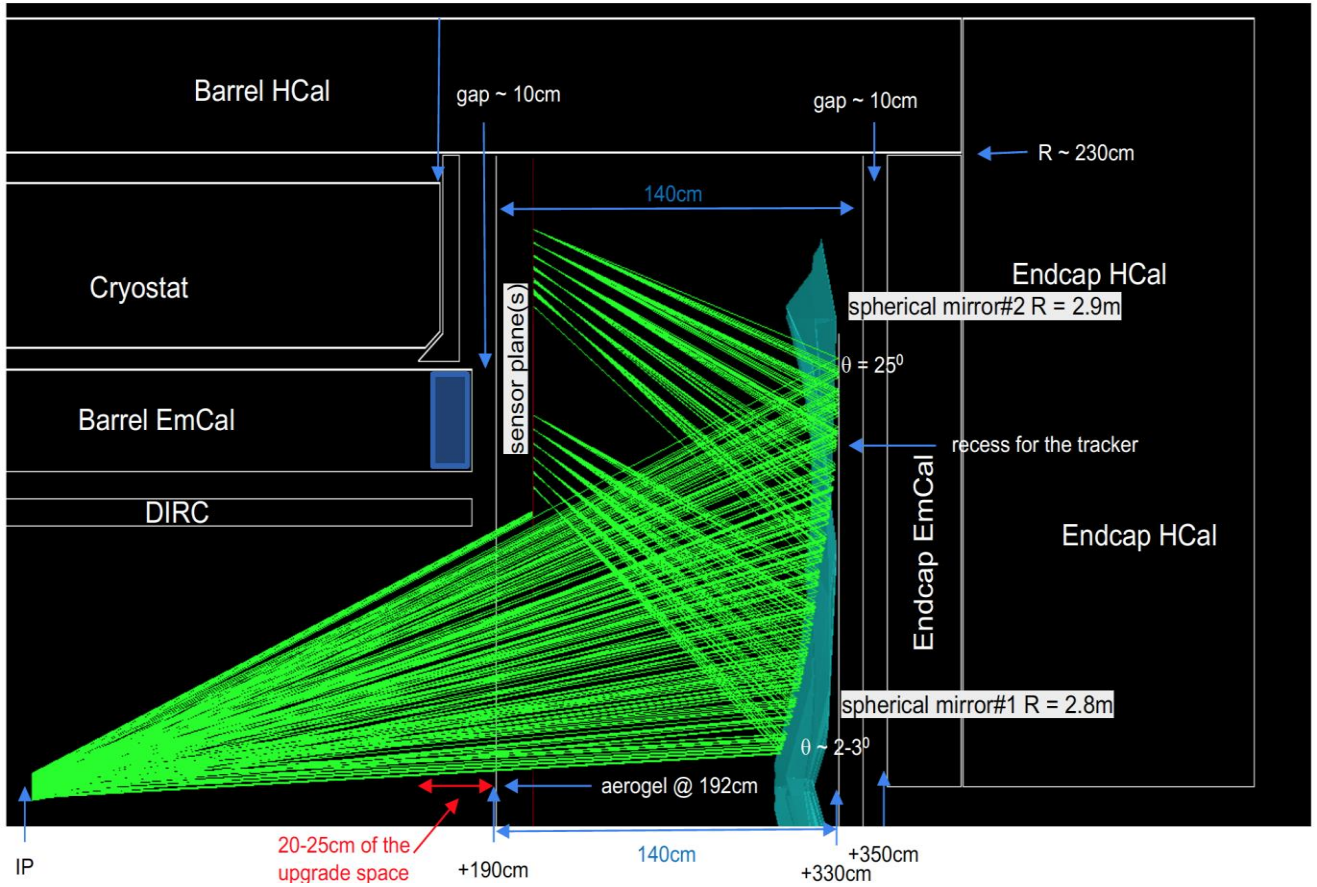
PID WBS Name	Detector	Channels
Barrel PID	hpDIRC	69,632
	TOF	8,600,000
Electron Endcap	mRICH	65,536
	TOF	920,000
Hadron Endcap	dRICH	344,064
	TOF	1,840,000
Far-Forward Detectors	Roman Pots	524,288
	B0 Detector	2.6M
	Off-Momentum Detectors	1.8M
Far-Backward Detectors	Low-Q^2 Tagger	4.6M
	Luminosity Monitor	268,441

Sensor technologies

Detector	Readout Technology candidates
Silicon Tracking	Si MAPS ITS3 like
GEM/MMG Layer	MGPD
Cylindrical MPGD *	MPGD
HP-DIRC	MAP/MT, MCPPMT
ECAL	SiPM
HCAL	SiPM
dRICH	PMT/SiPM
mRICH	PMT/SiPM
B0	Si MAPS ITS3 like (ITS2)
Off-Momentum	AC-LGAD (eRD24)
Roman Pots	AC-LGAD (eRD24)
ZDC	LGAD + ASIC eRD27
TOF	AC-LGAD

Significant SiPM Dark Currents expected in dRICH and pfRICH detectors

- Sensors are inside the 3T magnetic field,
  - SiPM sensors are envisioned.
  - Thresholds must be sensitive to single photons
- Dark Currents at this threshold ~3Khz / channel increasing to ~300Khz / channel after several years after which annealing will be performed
  - Mitigate by ~3 by applying timing window with respect to bunch crossing
  - Read up to 3.3Tbps into the DAQ computers but filter using
    - Software trigger
    - Potentially ML/AI if turns out practical
  - Software trigger reduces dark current volume to ~<15.5Gbps
  - As a potential mitigation the timing system & FELIX could be adopted to supply hardware trigger.

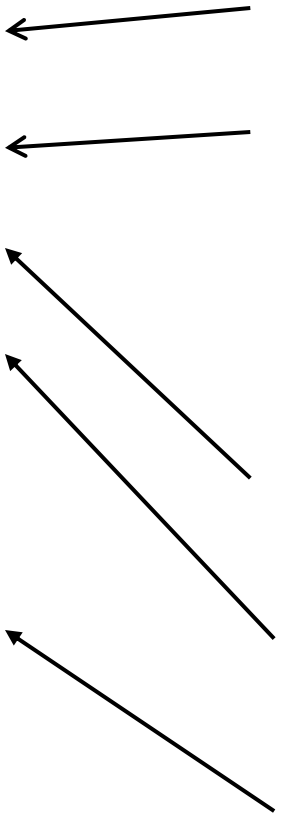


Data Volume Estimates

- Three different approaches, depending on goal
  - Maximum data volume which would change the character of the DAQ
    - dRICH and pfRICH resource limits are defined by worst-case SiPM dark currents
    - Far Backward resource limits are defined by expected data volume, but are low (just 1 FELIX board)
    - All other detectors are currently limited by connections, and have at least an order of magnitude excess rate capability which implies useful flexibility (e.g. disable feature extraction for tests, etc.)
    - Excursions beyond an order of magnitude would change DAQ, but might be addressable by software trigger (or even hybrid trigger system) but must be addressed as changes.
  - Detector Expert Estimates
    - These are the estimates presented in the Athena proposal
    - Physics estimates not uniform (yellow report, CDR, extrapolation from simulations for physics)
    - Estimates include engineer knowledge about likely detector issues.
  - Full simulations of proton beam gas, electron beam gas, synchrotron radiation and collisions.
    - These came together at the very end of the proposal process
    - Include detector response thresholds / instrumentation, but not fully simulated sensor response. Assume translation between hits→data volume

Detector Expert Estimates of data volumes

Detector	Channels	DAQ Input(Gbps)	DAQ Output(Gbps)
B0 Si	400M	<1	<1
B0 ac-lgad	500k	<1	<1
RP+Offm+ZDC	700k	<1	<1
FB Cal	4k	80	1
eCal	34k	5	5
hCal	39k	5.5	5.5
imCal	619M	4	4
Si Tracking	60B	5	5
Micromegas Tracking	66k	2.6	.6
GEM Tracking	28k	2.4	.5
uRWELL Tracking	50k	2.4	.5
dRICH	300k	1830	14
pfRICH	225k	1380	12
DIRC	100k	11	11
TOF	332k	3	.8
Totals		3400	61



Far forward detectors have low acceptance

Far backward do low Q tagging and Luminosity measurements but have high signal rate due to bremsstrahlung. The data is used primarily for histogramming, but also have subset that will be readout in concert with central detector collisions

Calorimeters with SiPM readout have higher thresholds and time-clustering in FEE

MAPS have enormous numbers of very quiet pixels. Also, they read out over 100-200ns time (<< 2us)

dRICH/pfRICH subject to SiPM dark currents

Key points regarding Athena's proposal (page 4)

- The dRICH in Athena
  - ~300k SiPM based channels (Another 225k channels in pfRICH)
  - Radiation dependent dark currents in the SiPM lead to high dark currents, indistinguishable from the single photon sensing required by the detectors
  - Data Volumes
    - Absolutely raw dark currents between: .2 – 18 Mbps per channel
    - Maximum absolute raw rate to dRICH: 5400 Gbps (4050 Gbps)
    - After application of time window on bunch crossings: 1800Gbps (1350 Gbps)
  - Athena approach was:
    - FEEs must apply the time window reduction
    - DAQ must provide sufficient bandwidth capability to read the data into the DAQ
    - DAQ must be able to produce a collision trigger (using calorimeters, presumably) and remove hits not associated with a collisions
    - ML/AI approach directly on the RICH data in FEP was mentioned as R&D, but not guaranteed.
  - Note, that the same dynamic is at play for the far backward detectors. They produce a low volume of histogrammed data, but also a total zs data volume that could approach 50-100Gbps due to high bremsstrahlung rate and would be reduced in the same fashion.

Conclusion / path forward / question

- Finalize sensor
- If SiPMT
  - Update number of channels
  - Evaluate rates
  - Updates number of fibers and aggregators
  - Update budget for handling of dark count

  - ASIC development needed ?