

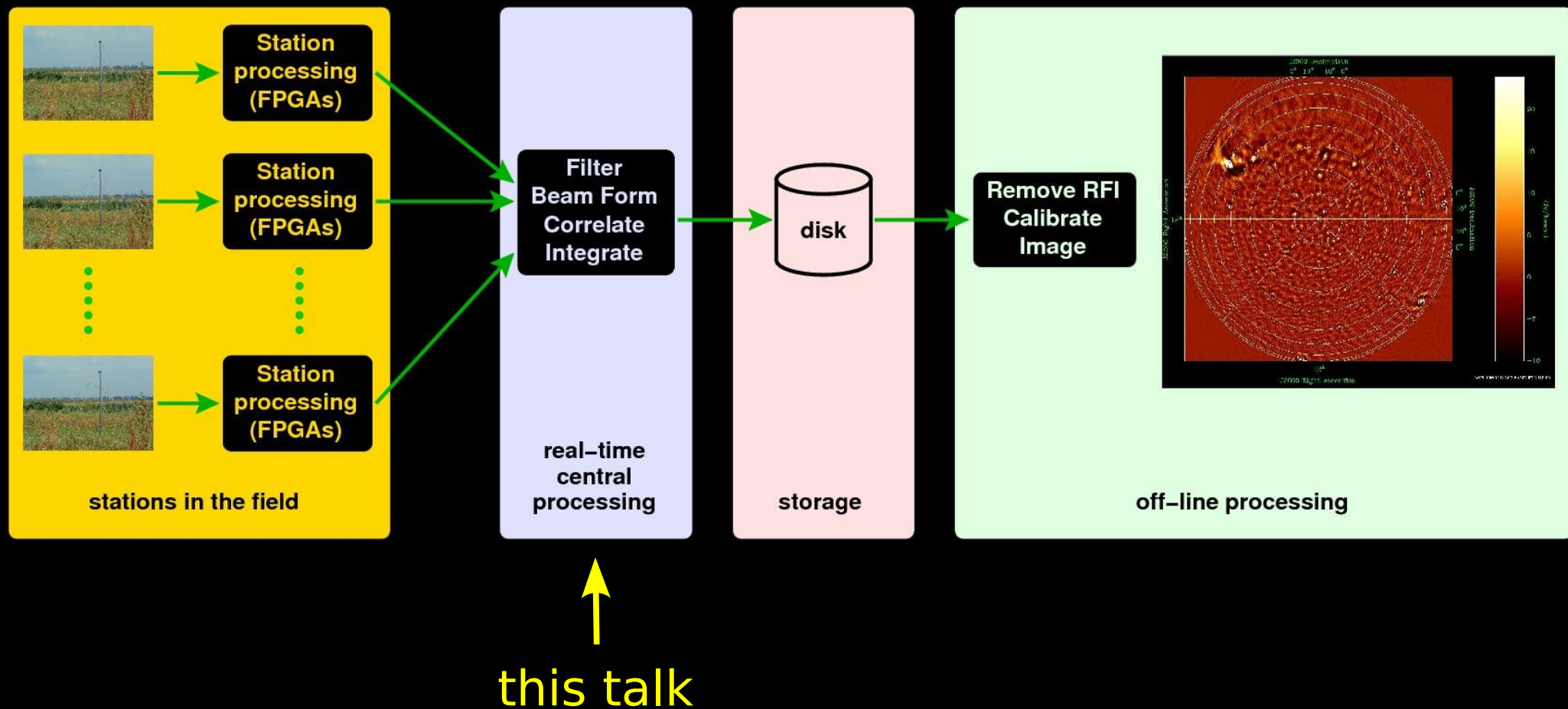


LOFAR Real-Time Central Processing

John W. Romein
P. Chris Broekema
Jan David Mol
Rob V. van Nieuwpoort

*Stichting ASTRON (Netherlands Institute for Radio Astronomy)
Dwingeloo, the Netherlands*

LOFAR Real-Time Central Processing



Outline

- ❑ “Correlator” capabilities
 - ❑ \gg just correlations
- ❑ performance

Central Processing

- ❑ correlator combines data of all stations
- ❑ software
 - ❑ different observation modes require flexibility
 - ❑ standard imaging
 - ❑ pulsar survey
 - ❑ known pulsar
 - ❑ epoch-of-reionization
 - ❑ transients
 - ❑ very high-energy particles
 - ❑ ultra high-energy particles
 - ❑ ...
 - ❑ concurrent observations
 - ❑ piggy-back observations
- ❑ need supercomputer
- ❑ real time (& off-line)

IBM Blue Gene/P

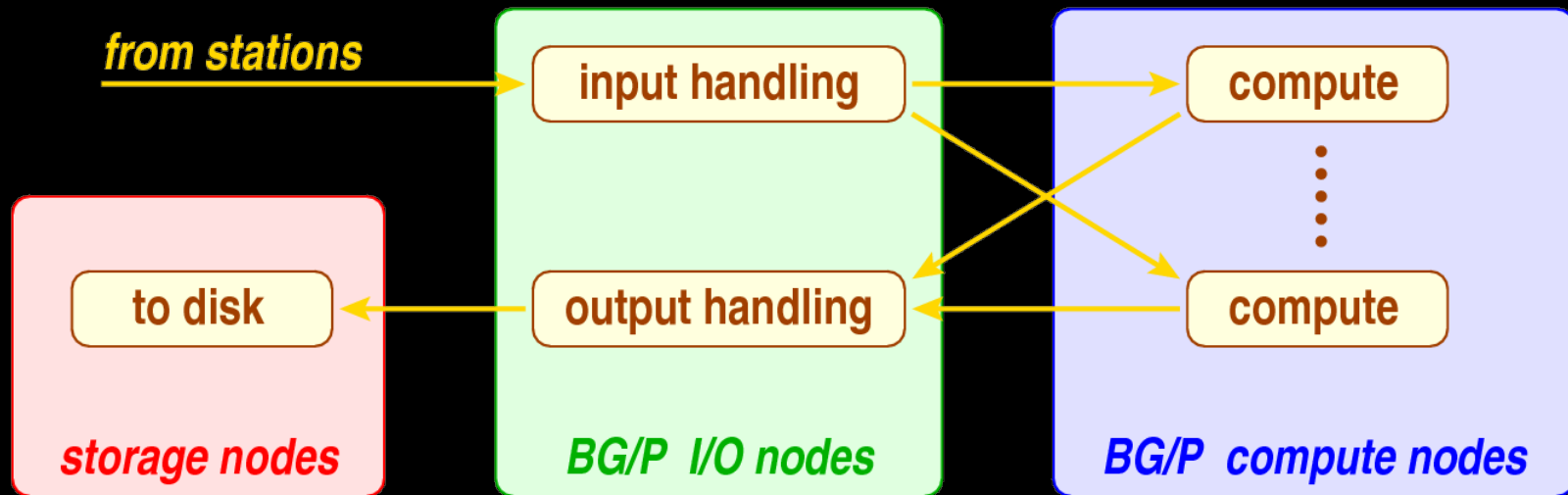


- ❑ use 1 of 3 racks
- ❑ 4096 cores + 64 I/O nodes
- ❑ fast networks

Definition of “Subband”

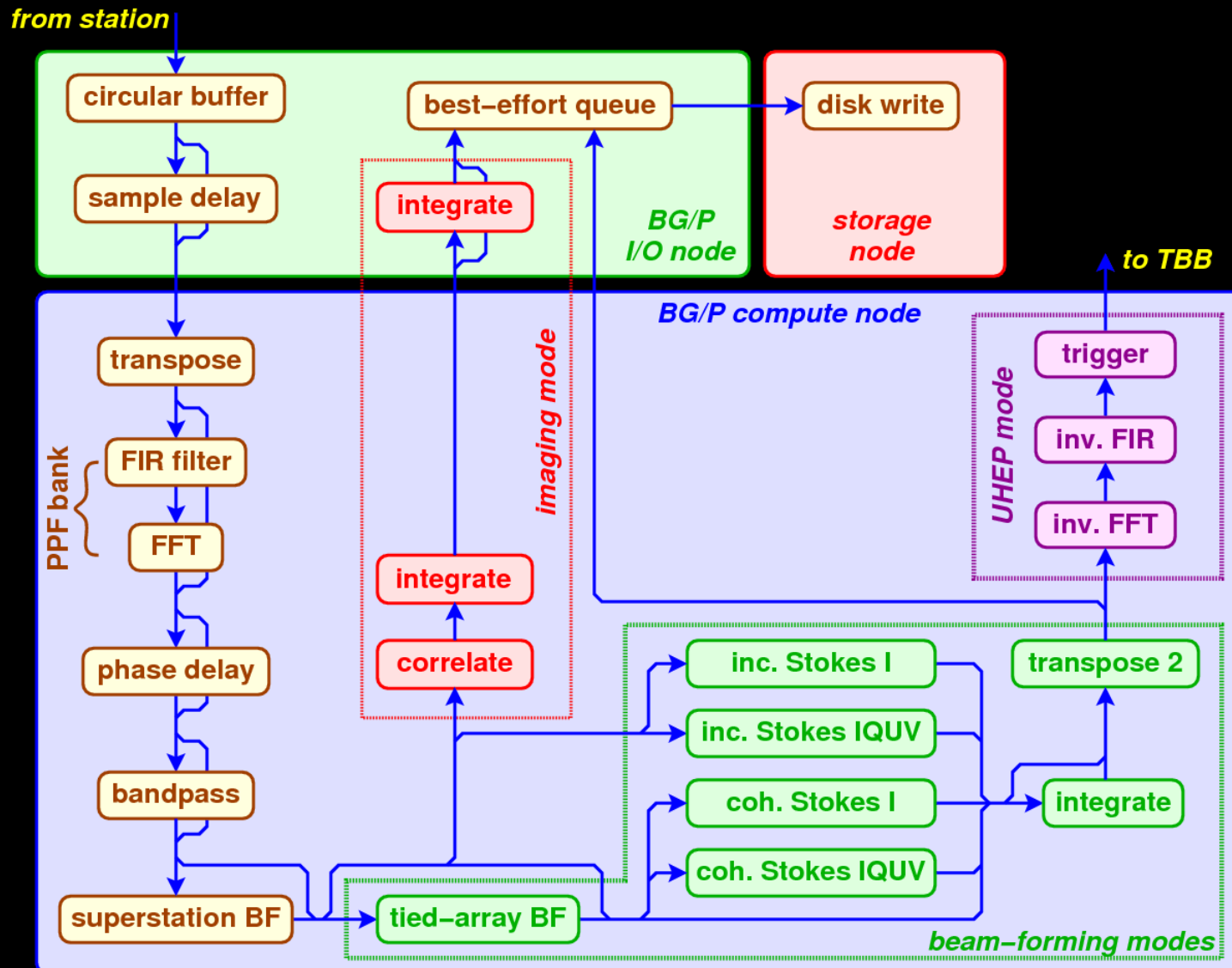
- ❑ subband properties:
 - ❑ frequency band (e.g., 59.9–60.1 MHz)
 - ❑ beam direction (e.g., Cas A)
 - ❑ dual pol (X, Y)
- ❑ up to 248 subbands (16-bit samples)

The BG/P Correlator

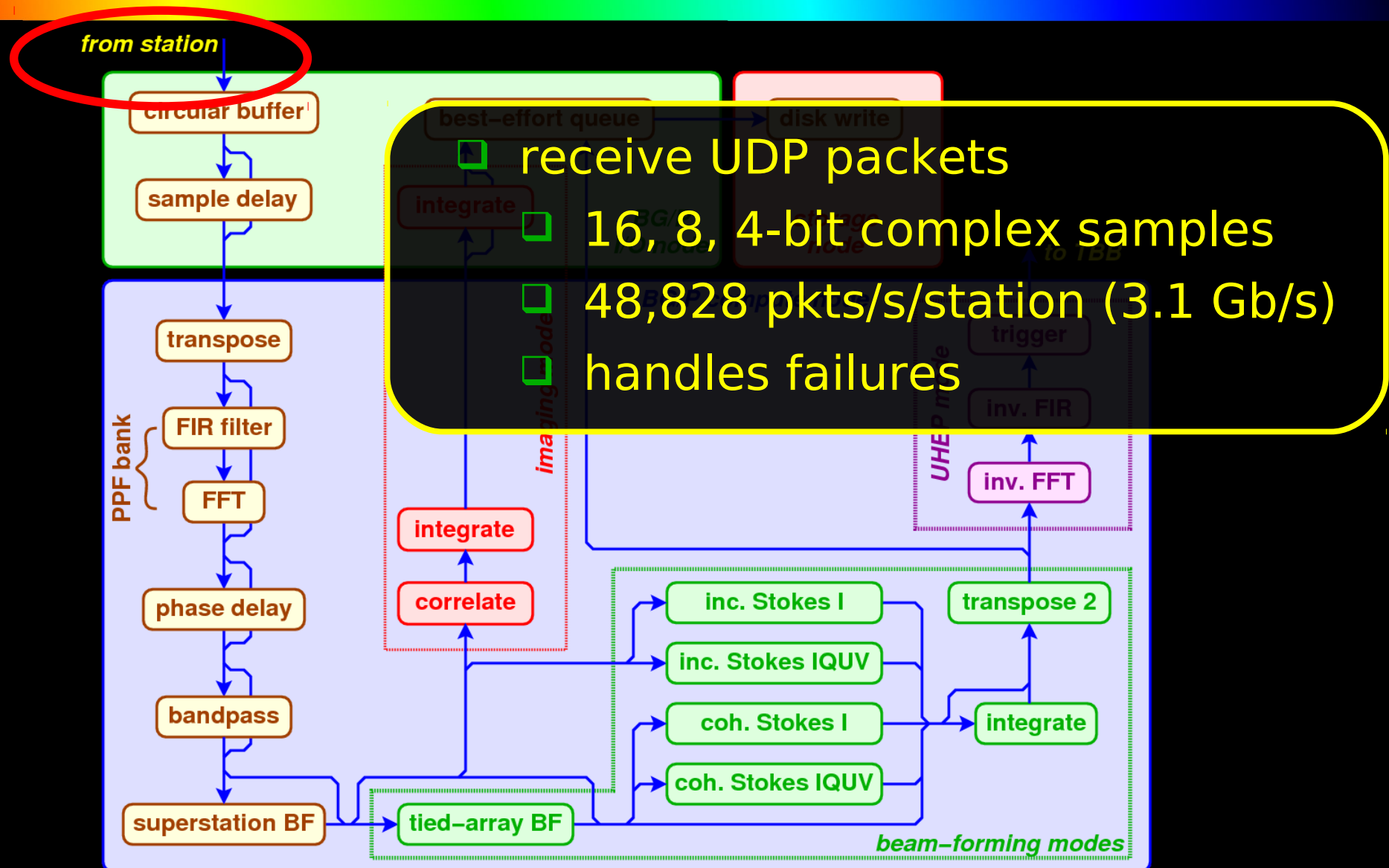


- three distributed applications/platforms

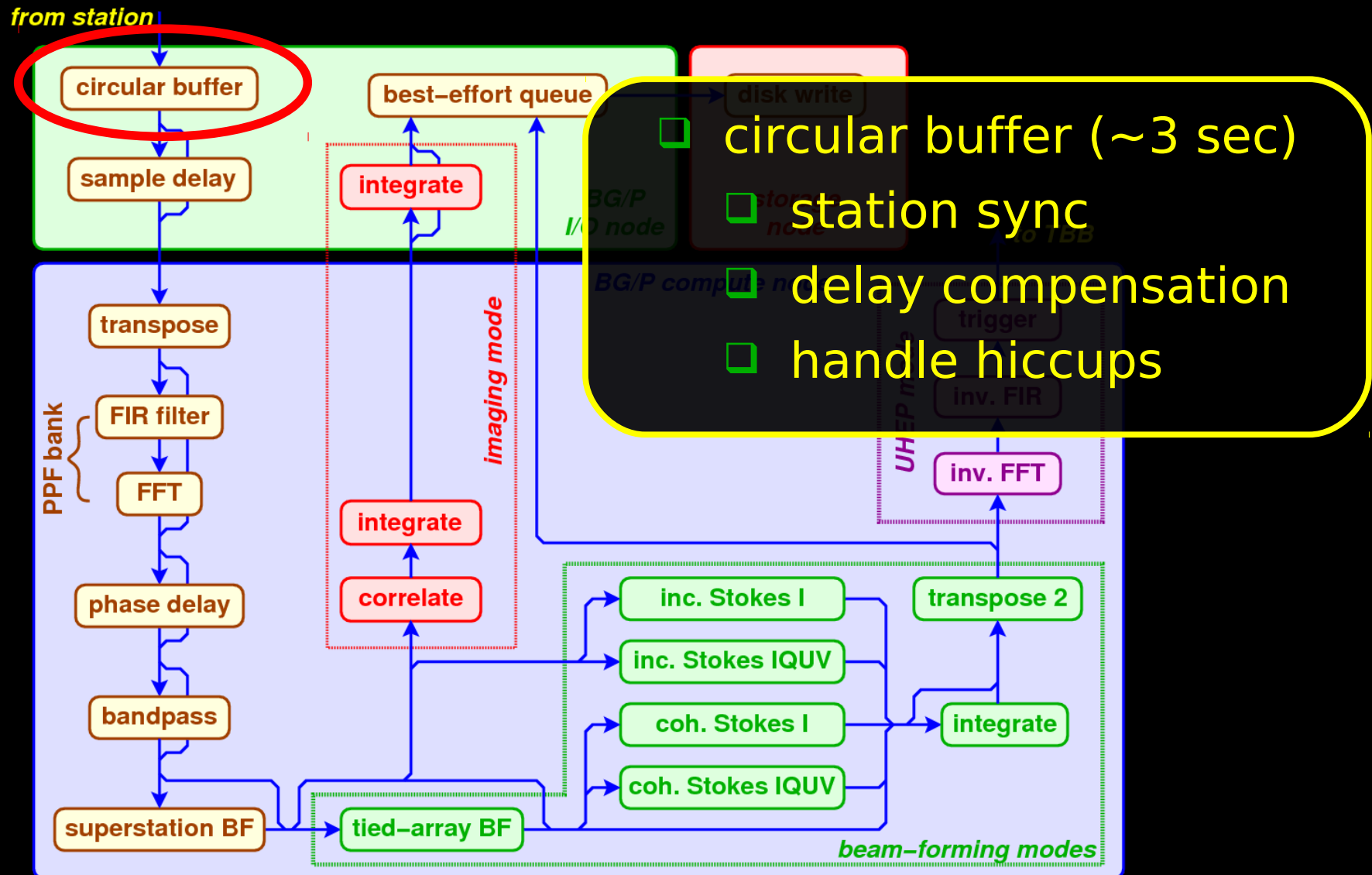
Pipeline Overview



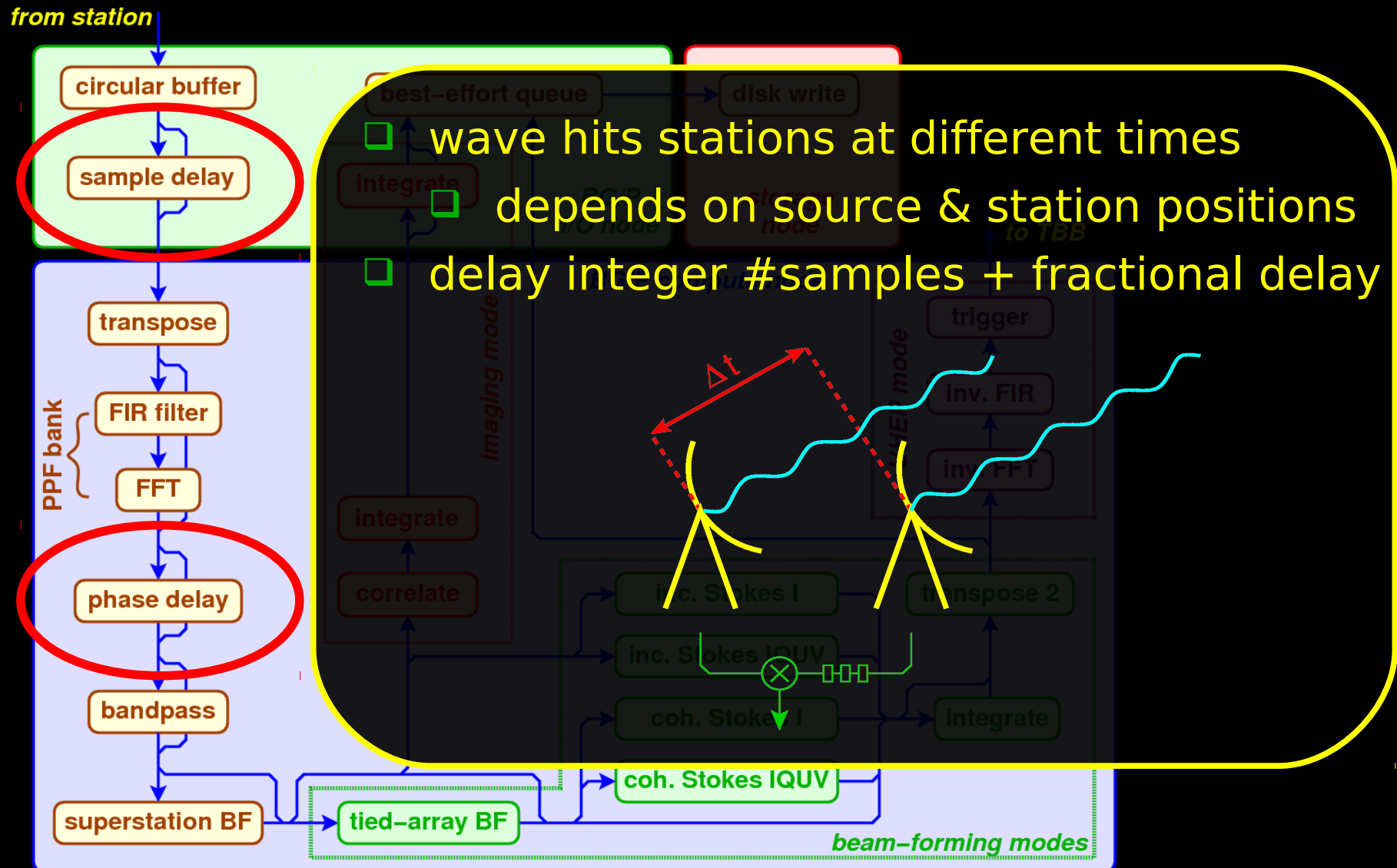
Station Data Receipt



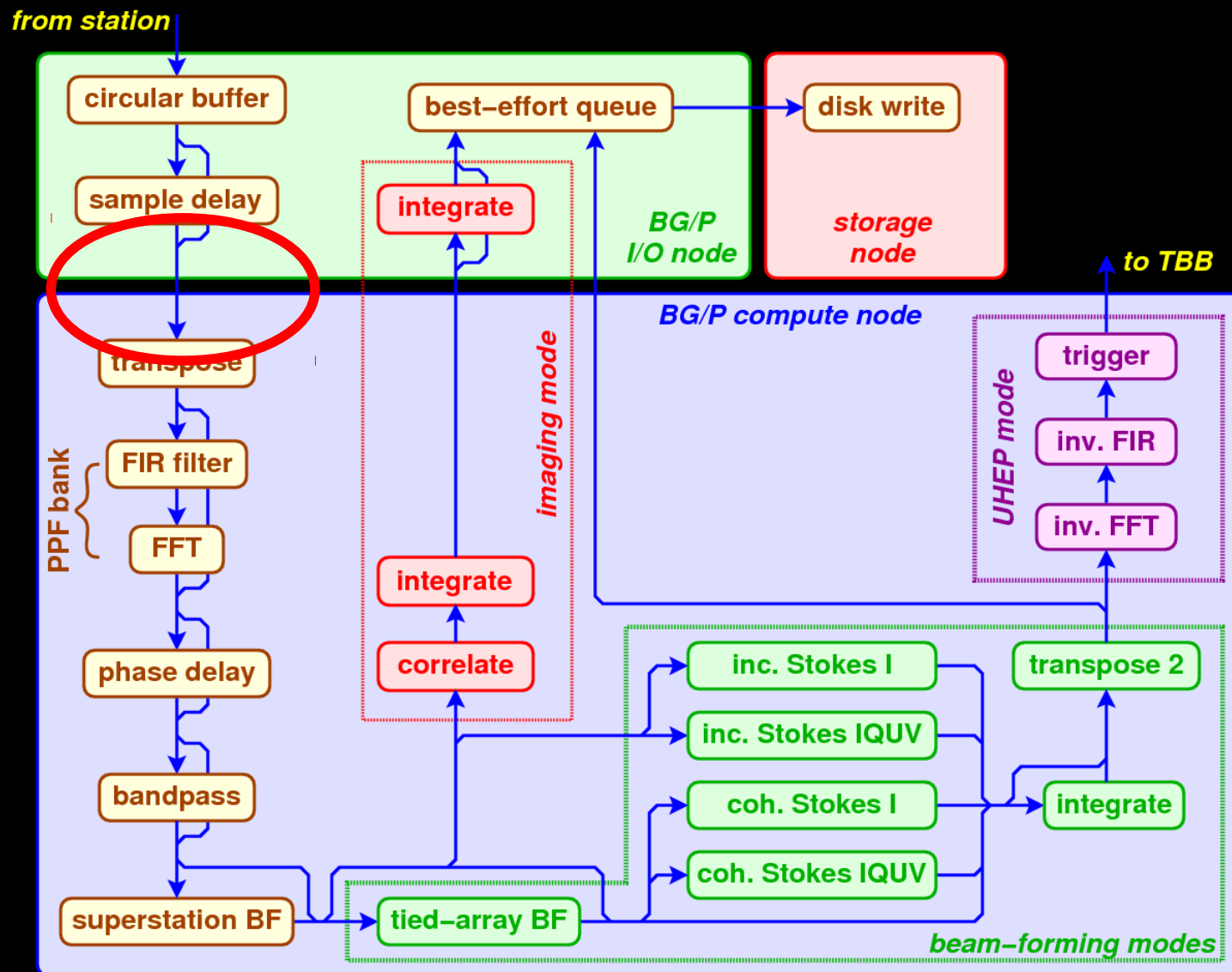
Circular Buffer



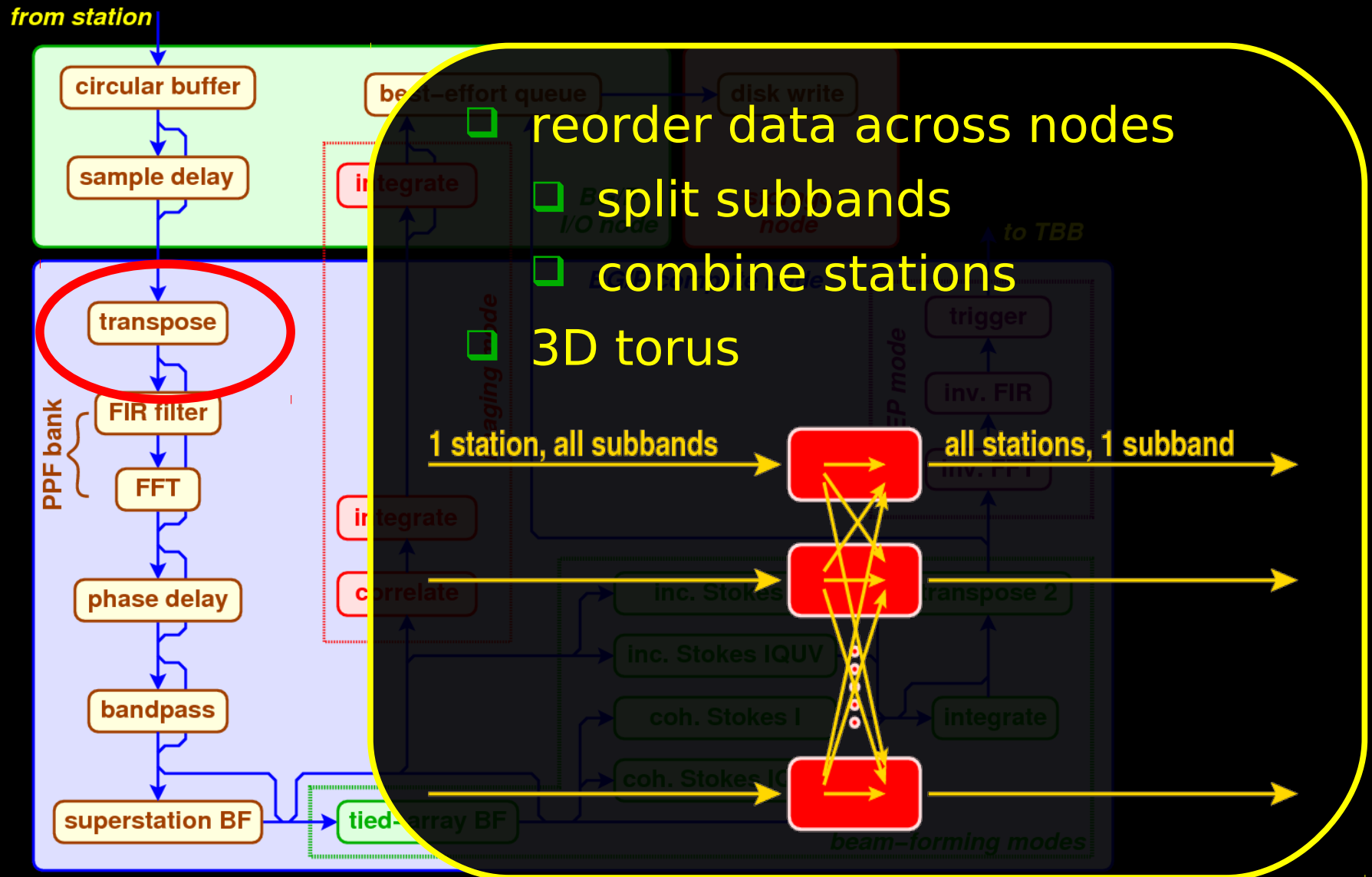
Delay Compensation



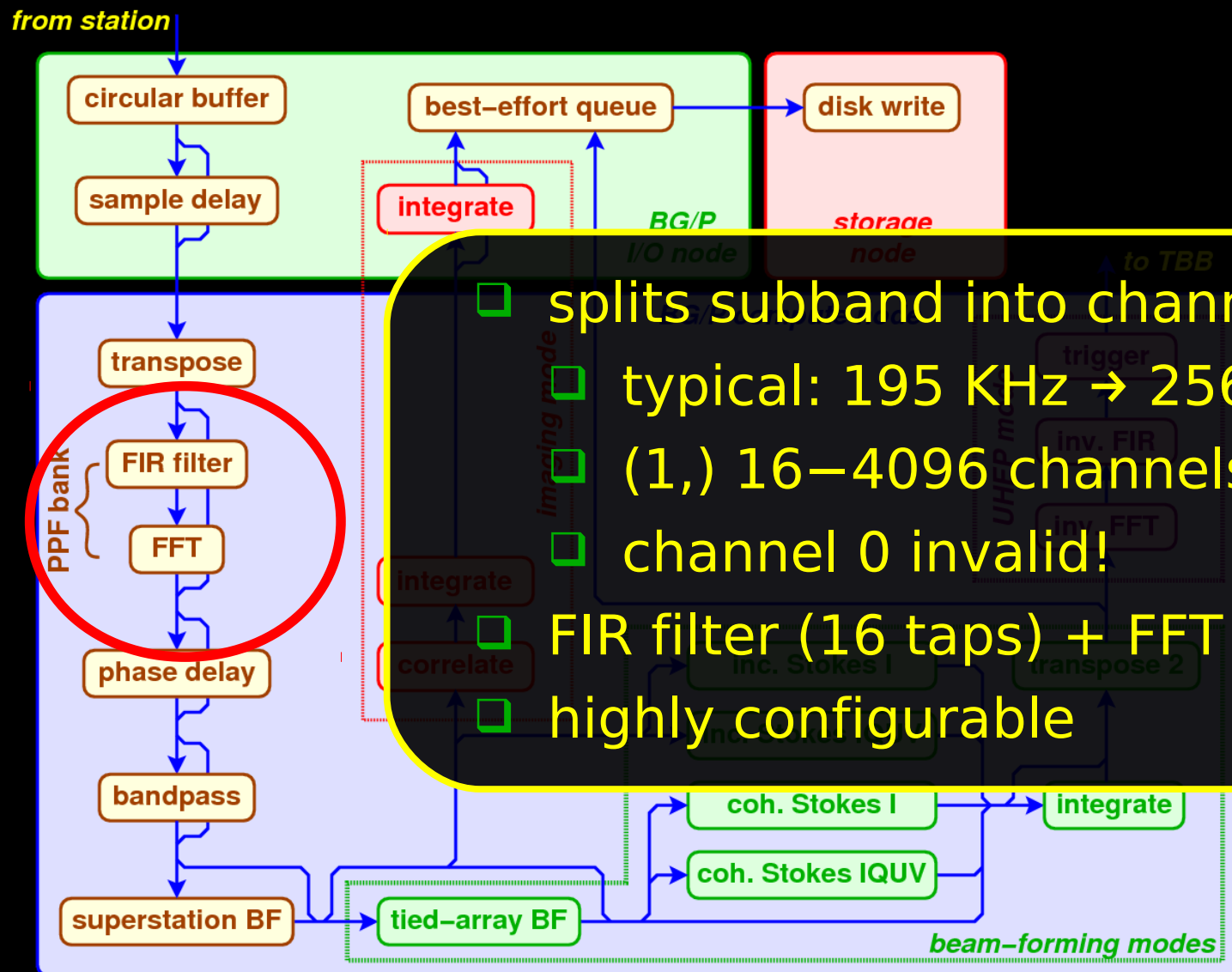
I/O Node → Compute Node



Transpose

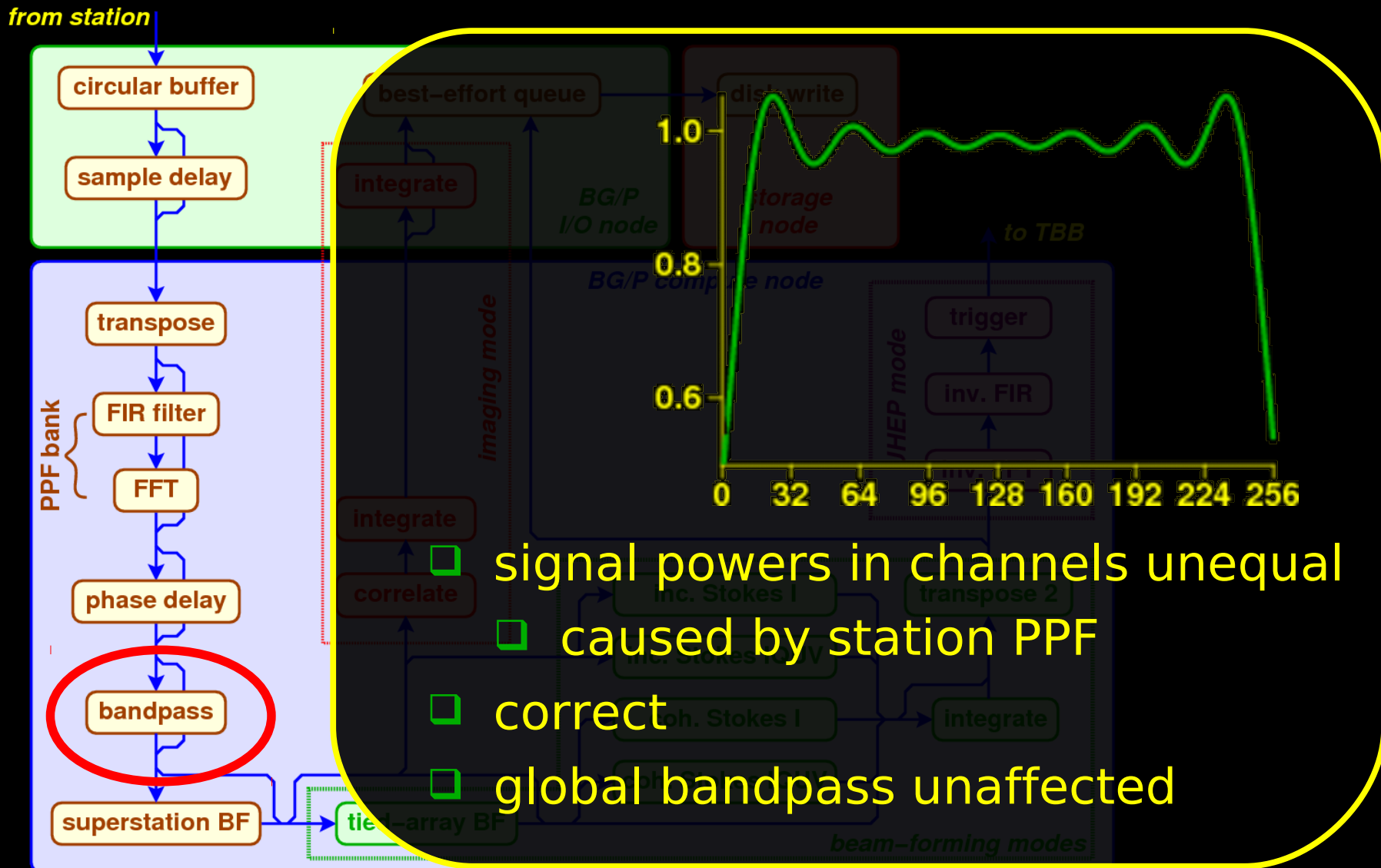


Poly-Phase Filter Bank

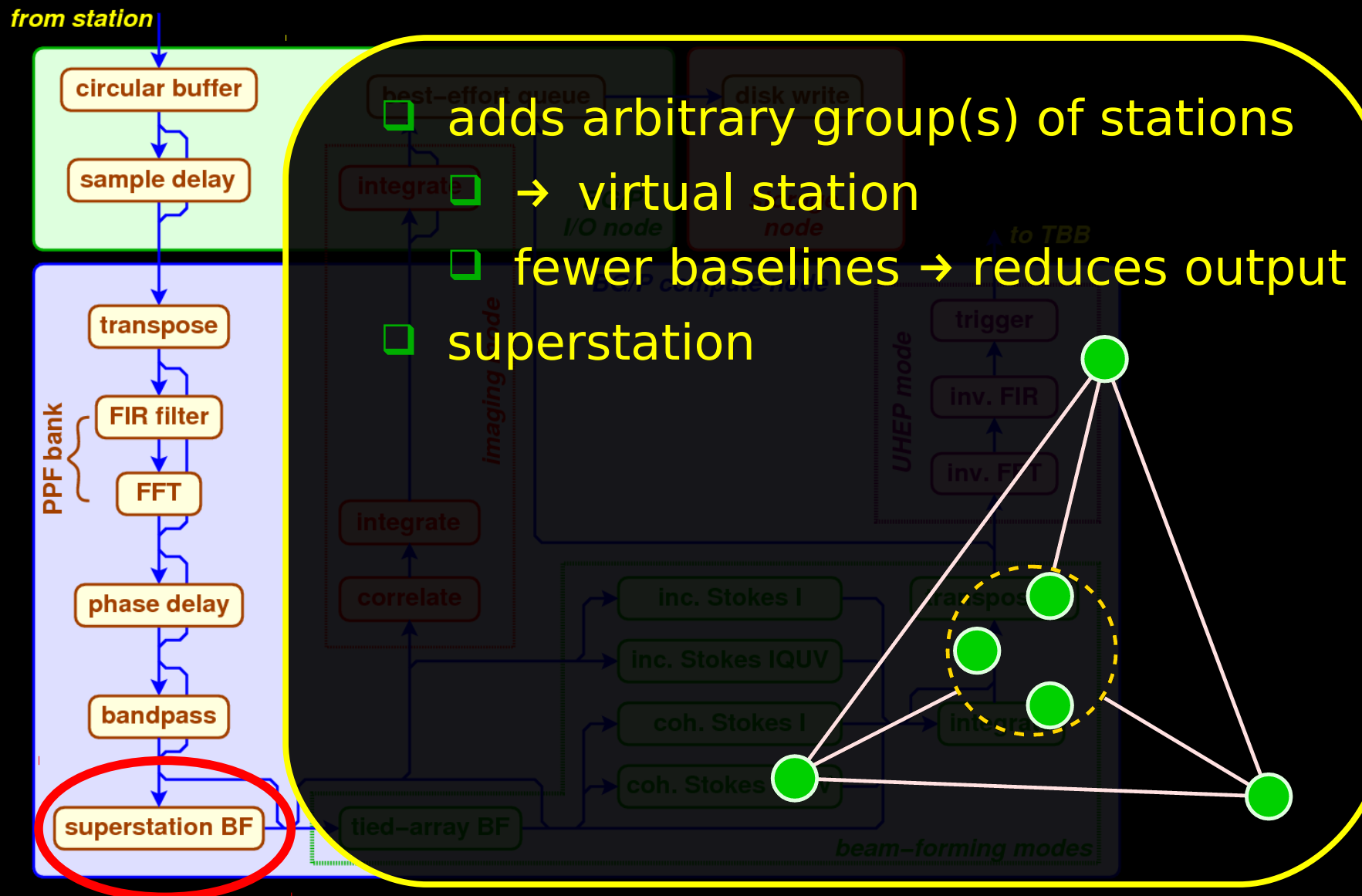


- splits subband into channels
- typical: 195 KHz \rightarrow 256 * 762 Hz
- (1,) 16–4096 channels
- channel 0 invalid!
- FIR filter (16 taps) + FFT
- highly configurable

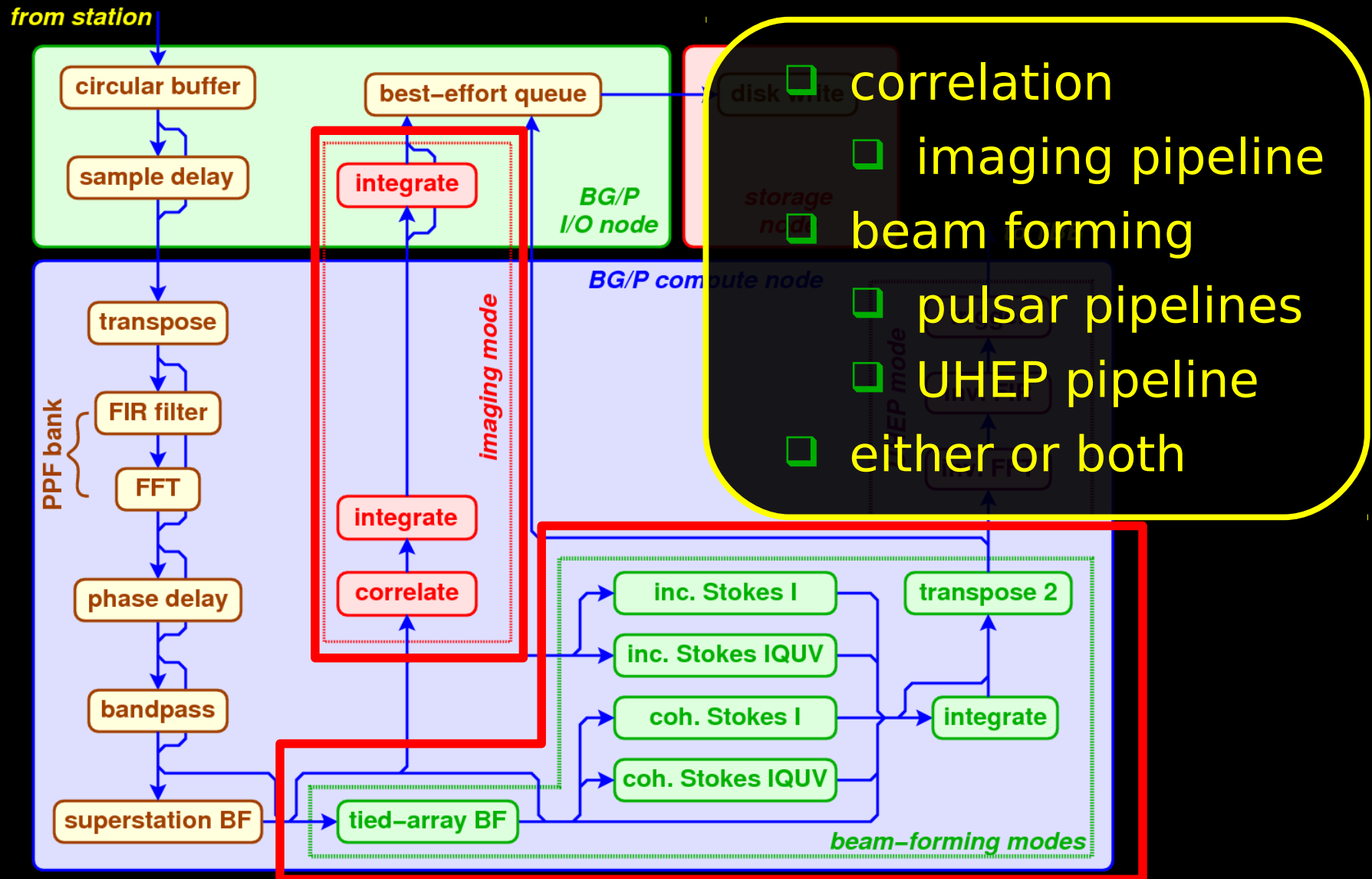
Bandpass Correction



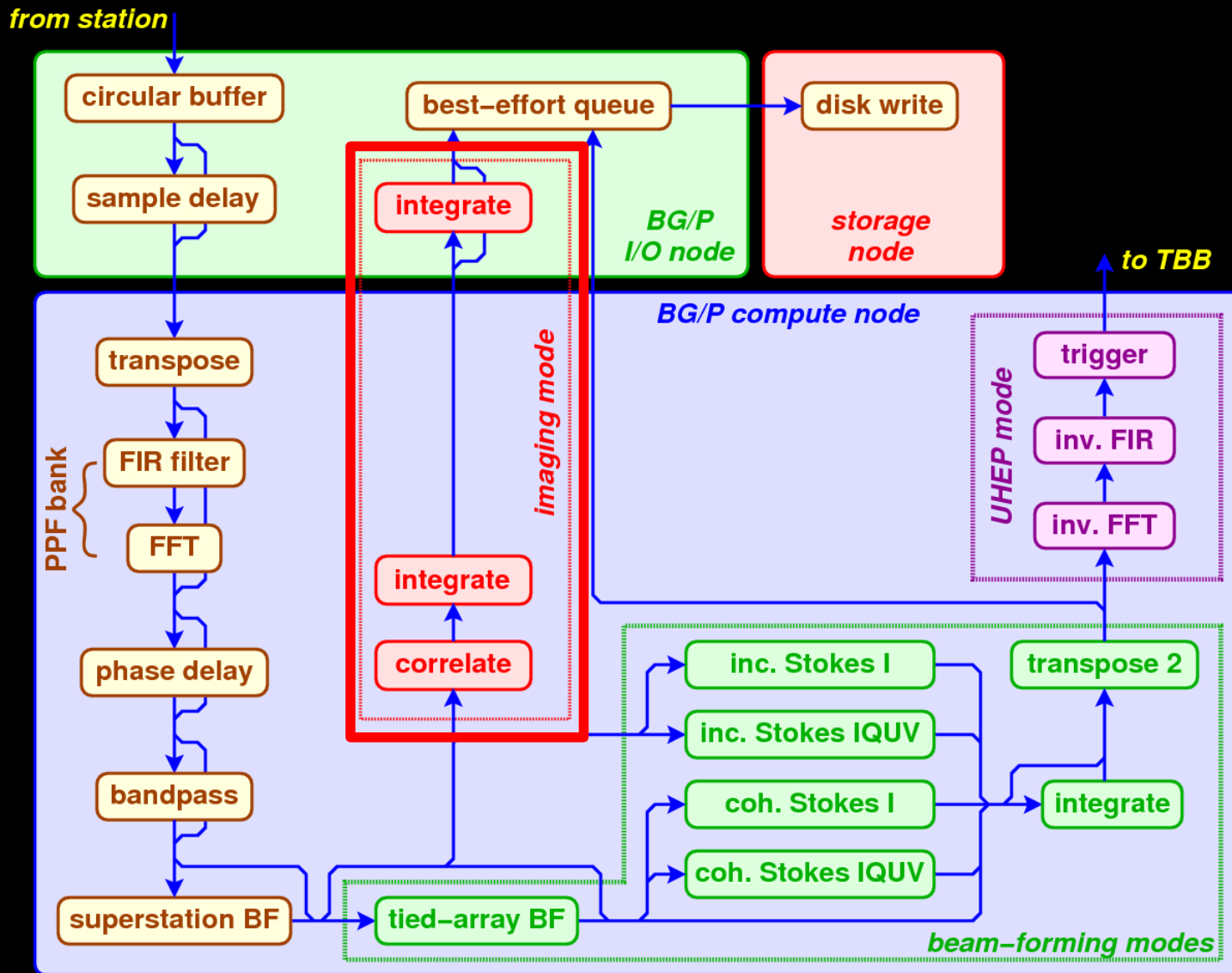
SuperStation Beam Forming



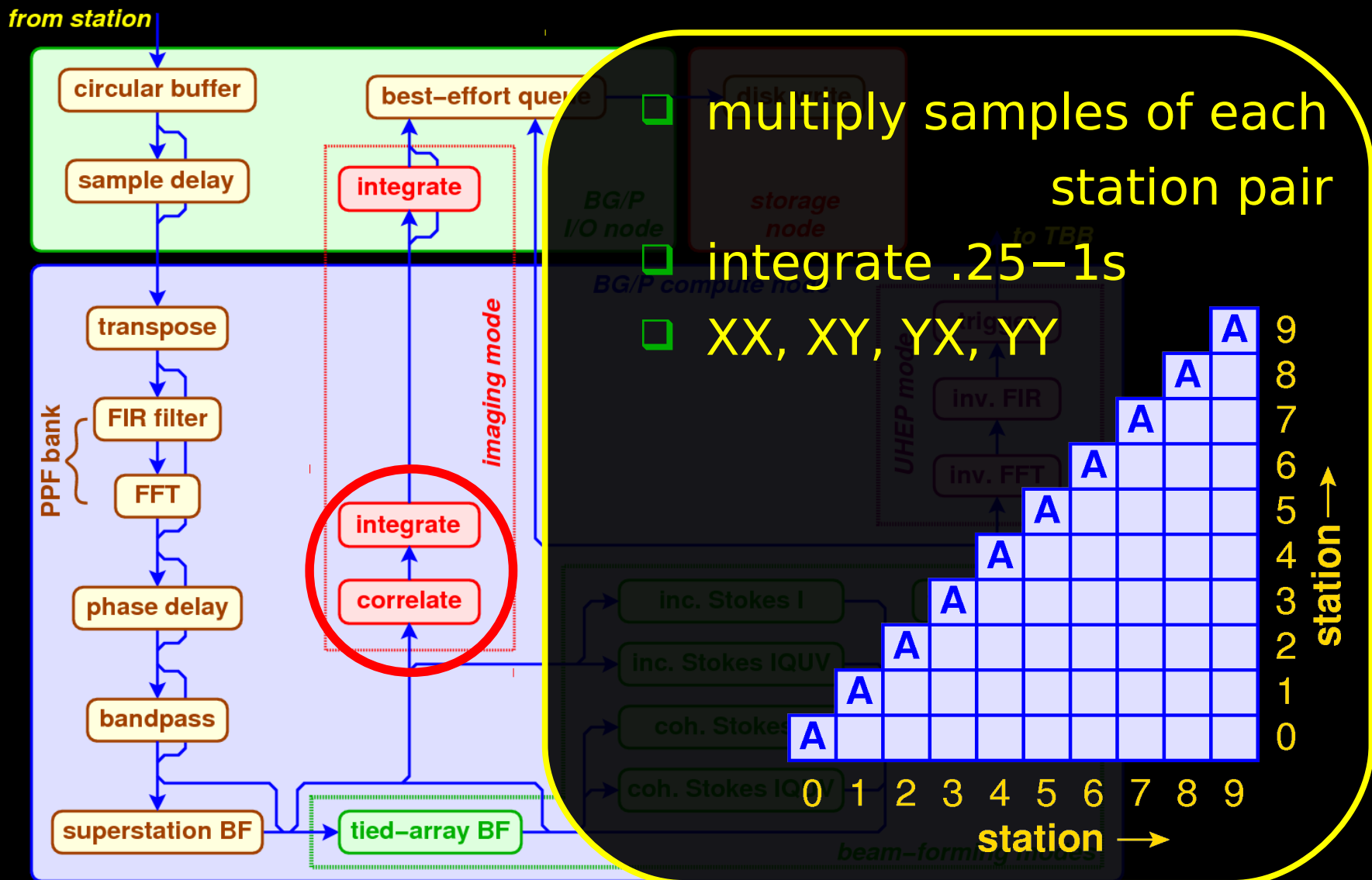
Pipeline diversion



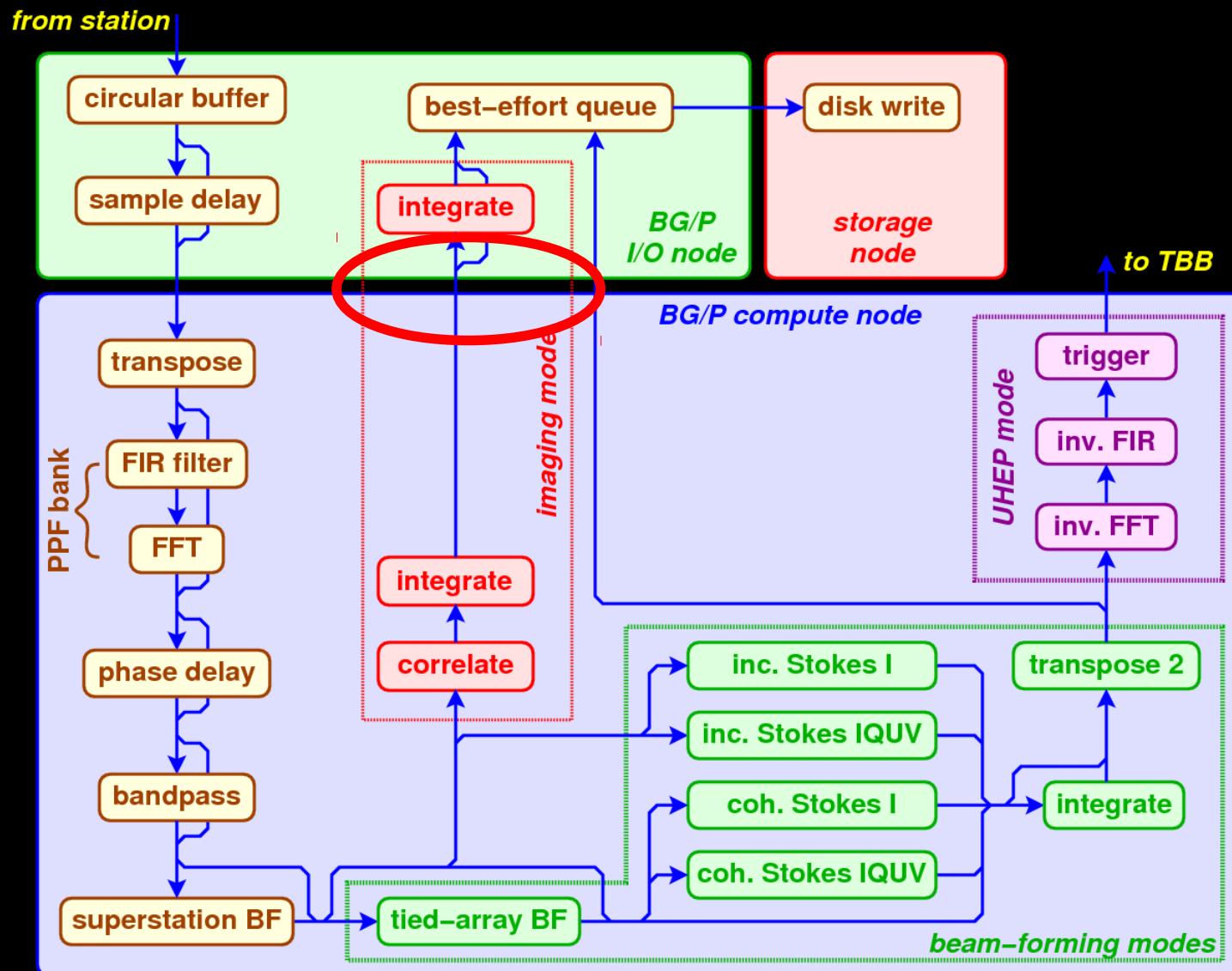
Correlation Pipeline



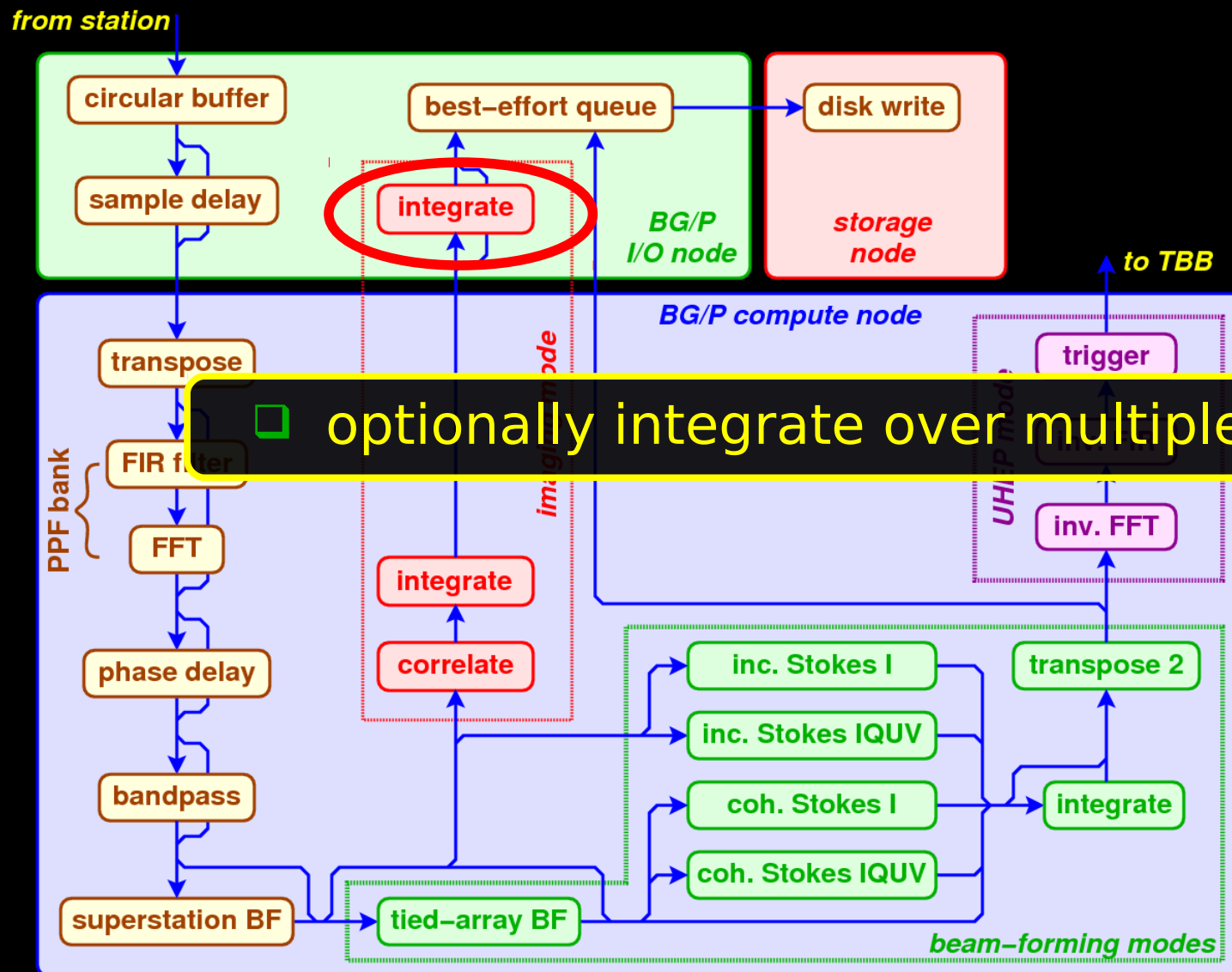
Correlation



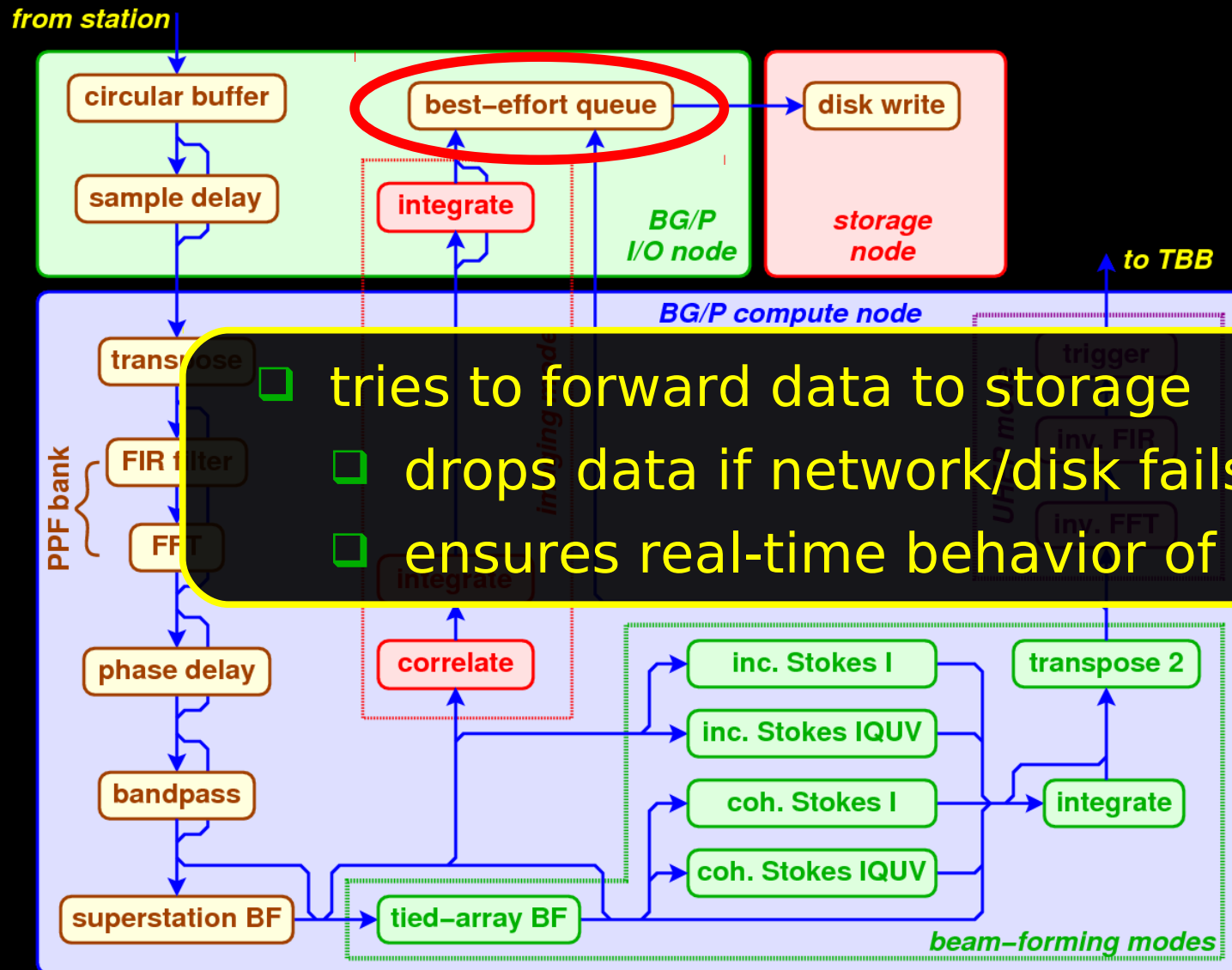
Compute Node → I/O Node



Further Integration

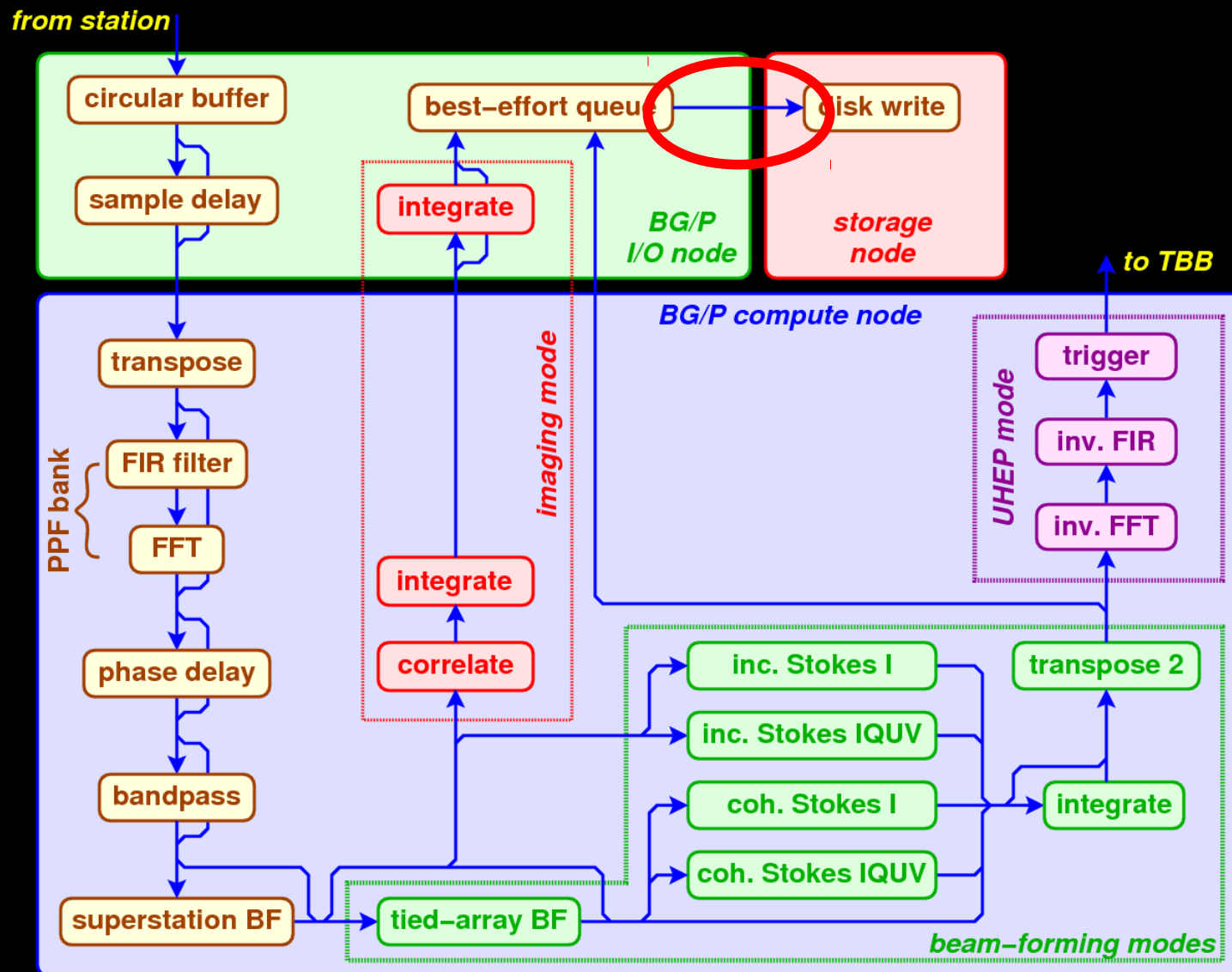


Best-Effort Queue

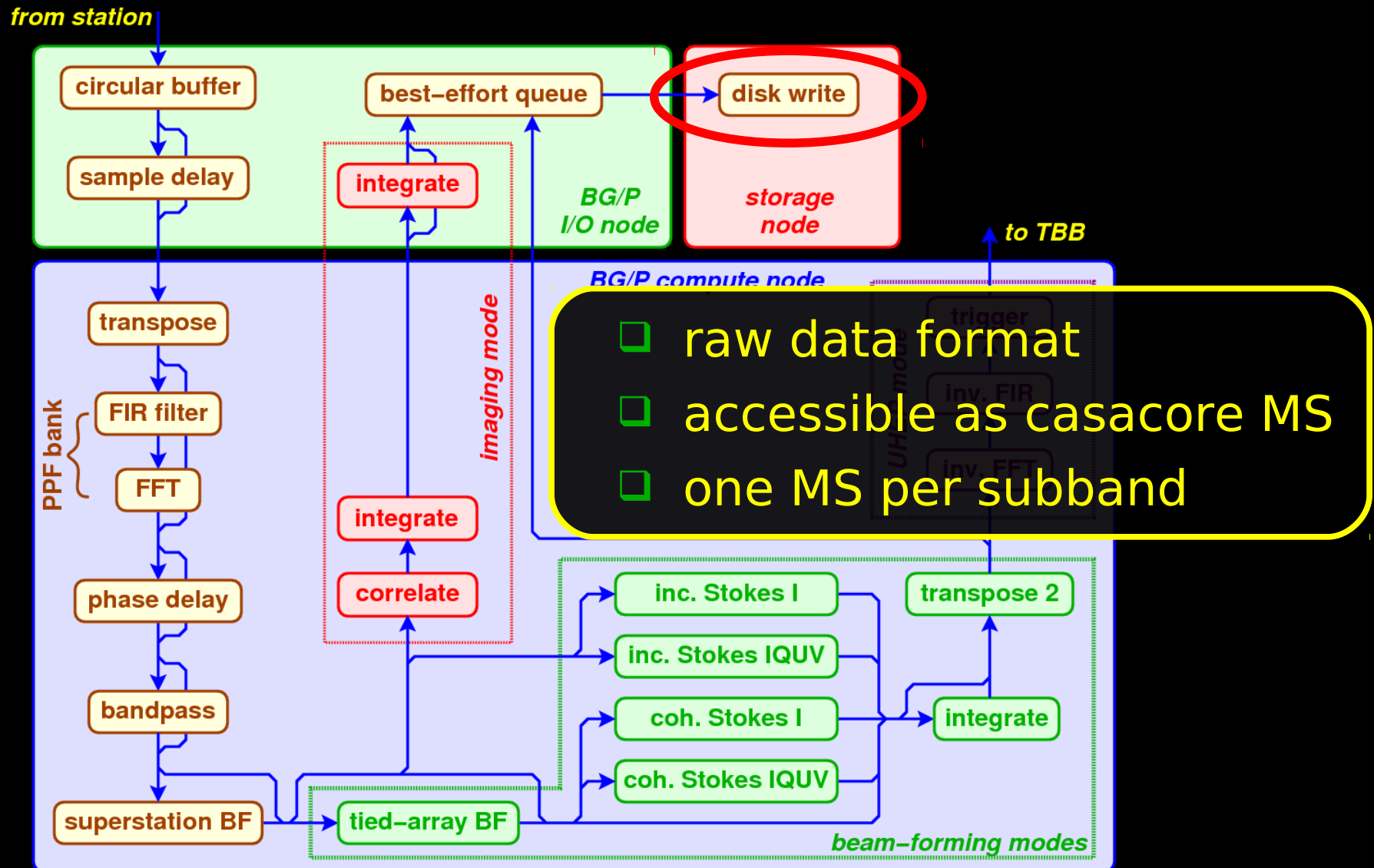


- ❑ tries to forward data to storage
- ❑ drops data if network/disk fails
- ❑ ensures real-time behavior of correlator

I/O Node → Storage Node

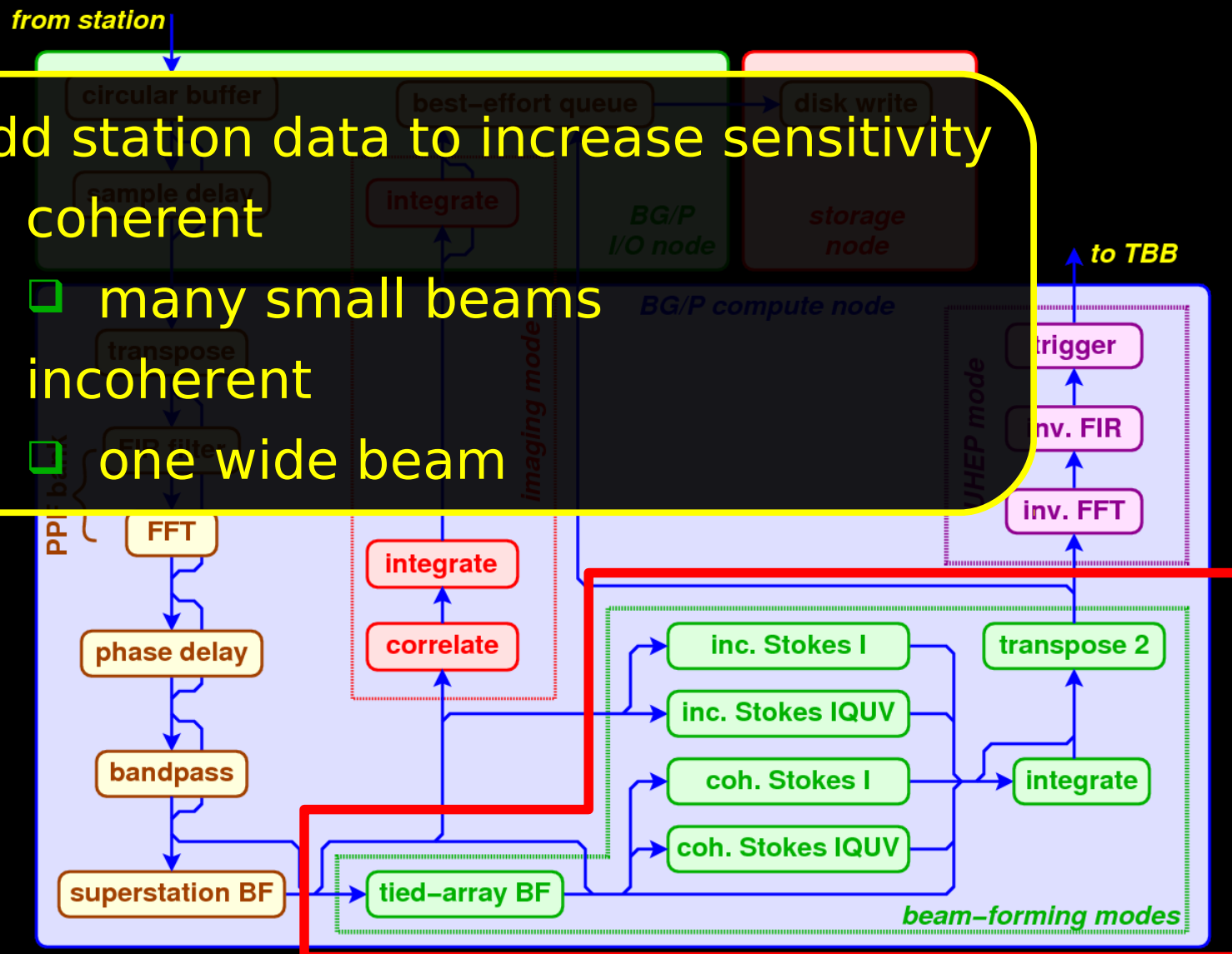


Write to Disk



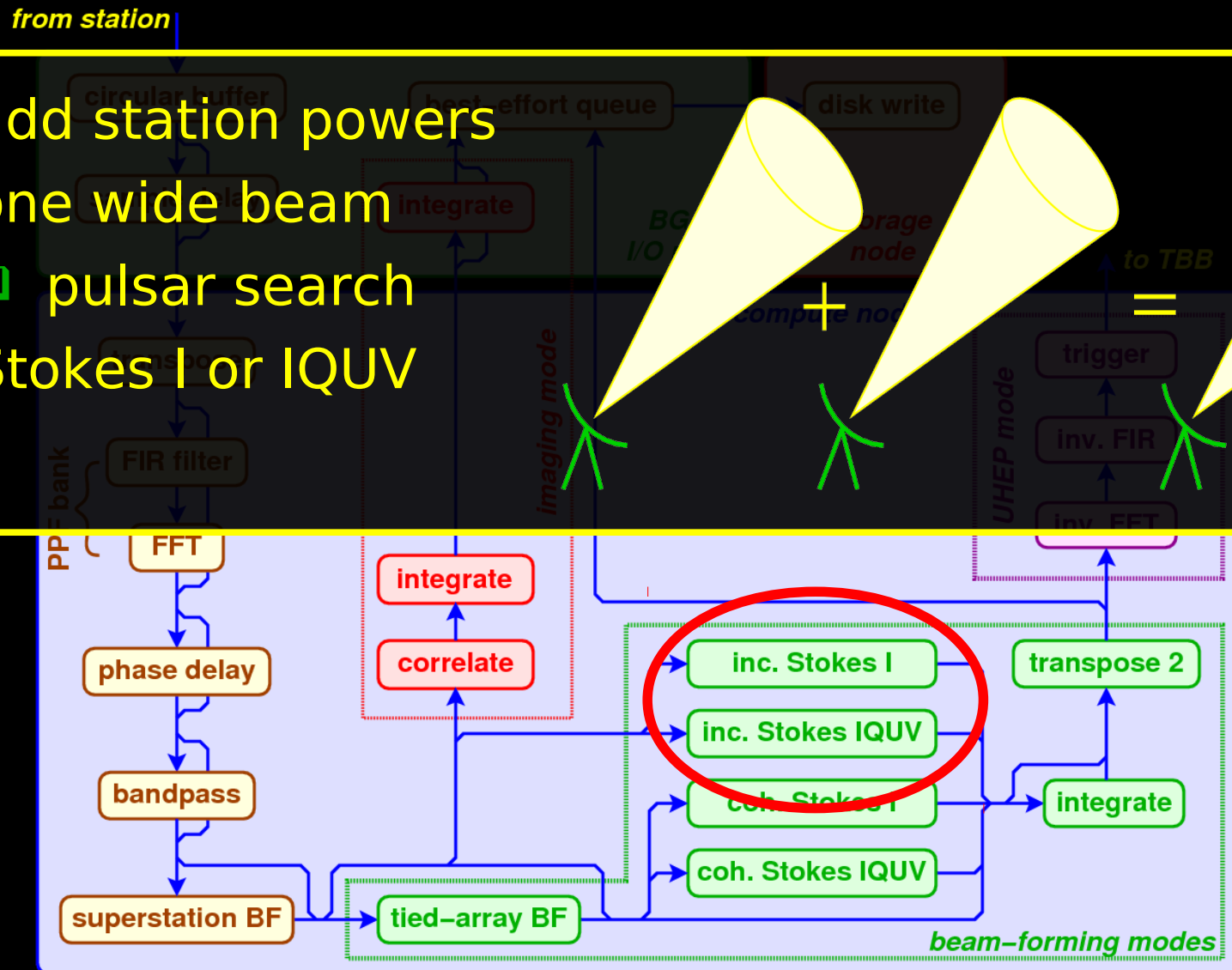
Beam Forming Pipelines

- ❑ add station data to increase sensitivity
- ❑ coherent
 - ❑ many small beams
- ❑ incoherent
 - ❑ one wide beam

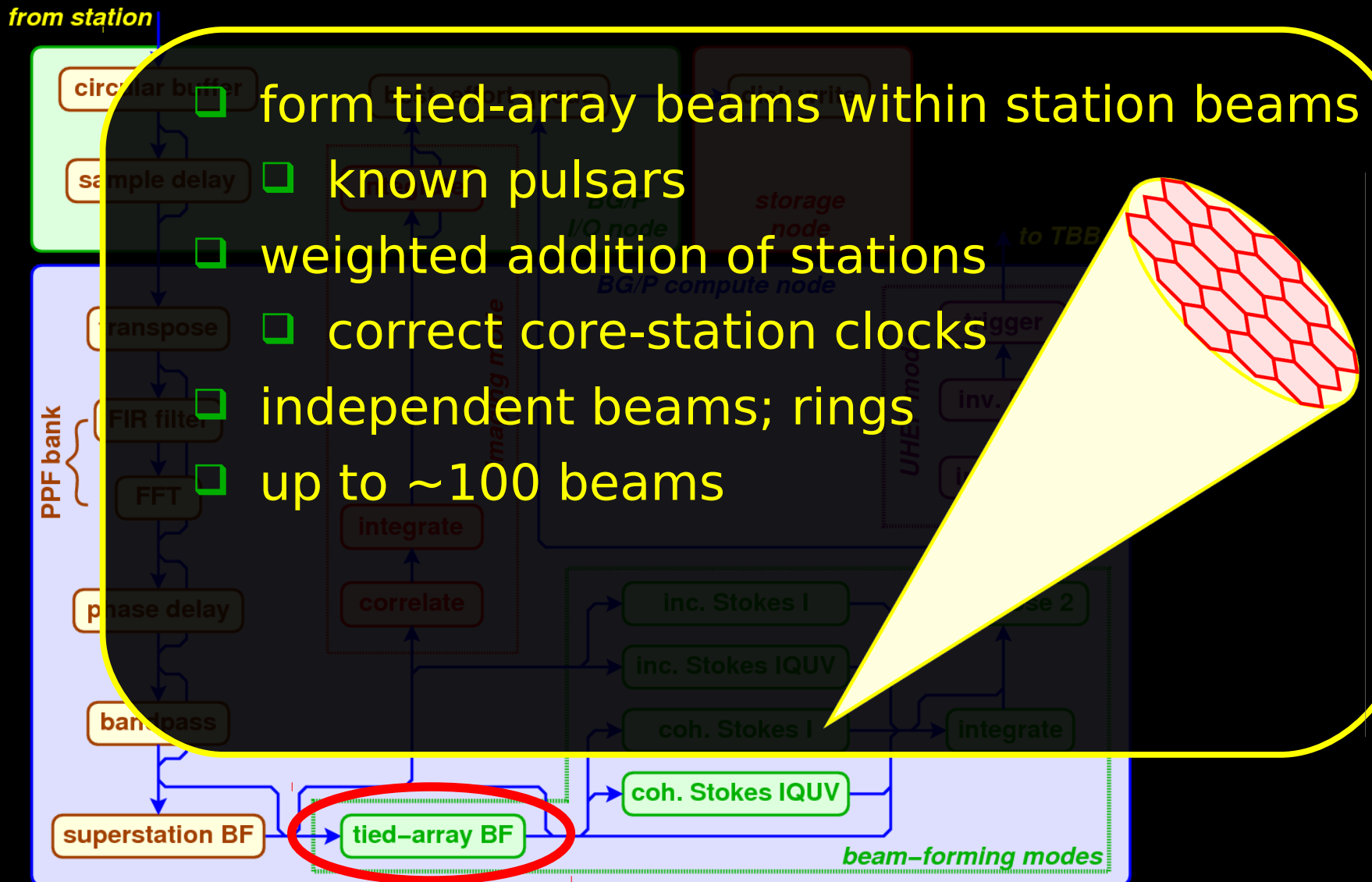


Incoherent Beam Forming

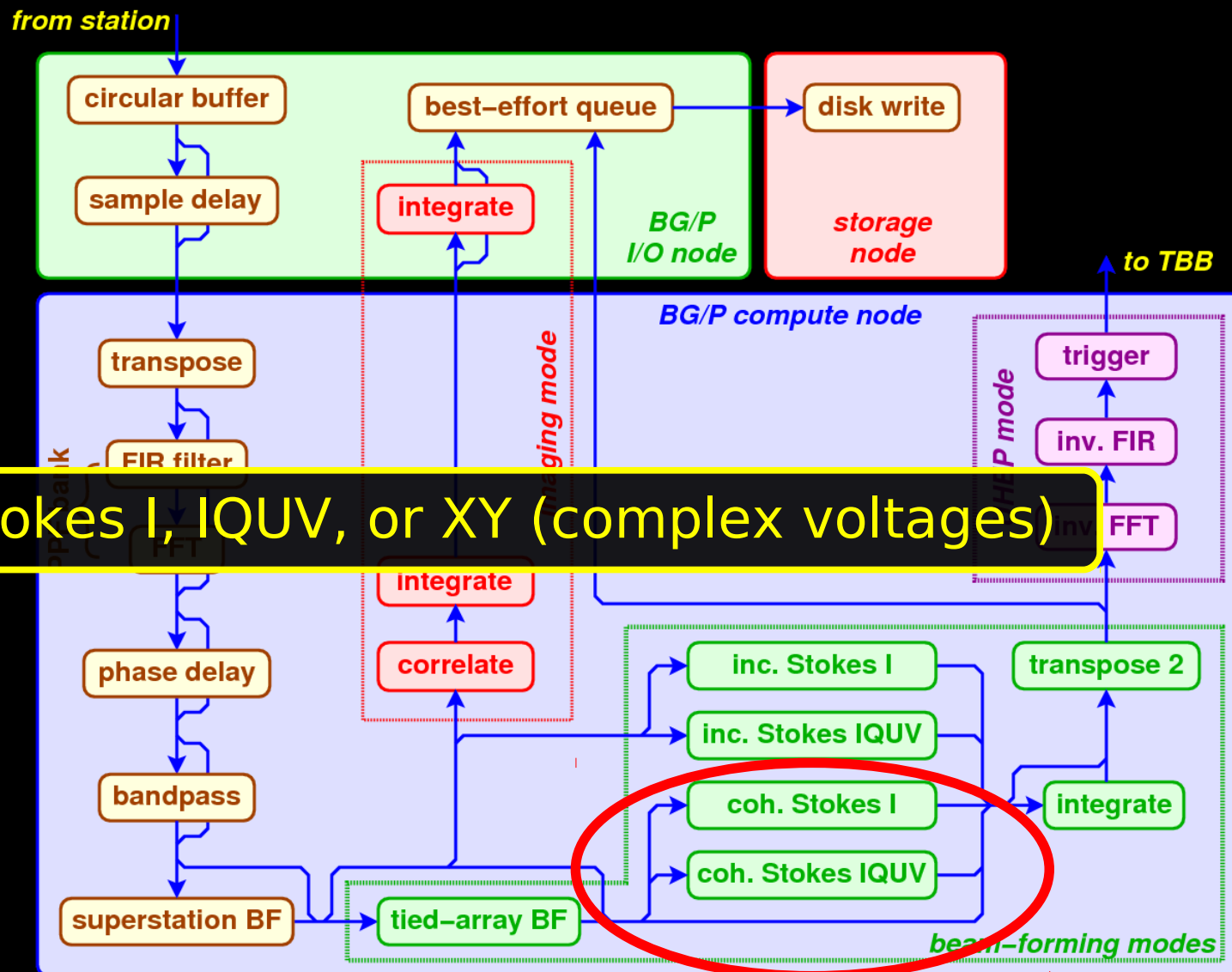
- ❑ add station powers
- ❑ one wide beam
 - ❑ pulsar search
- ❑ Stokes I or IQUV



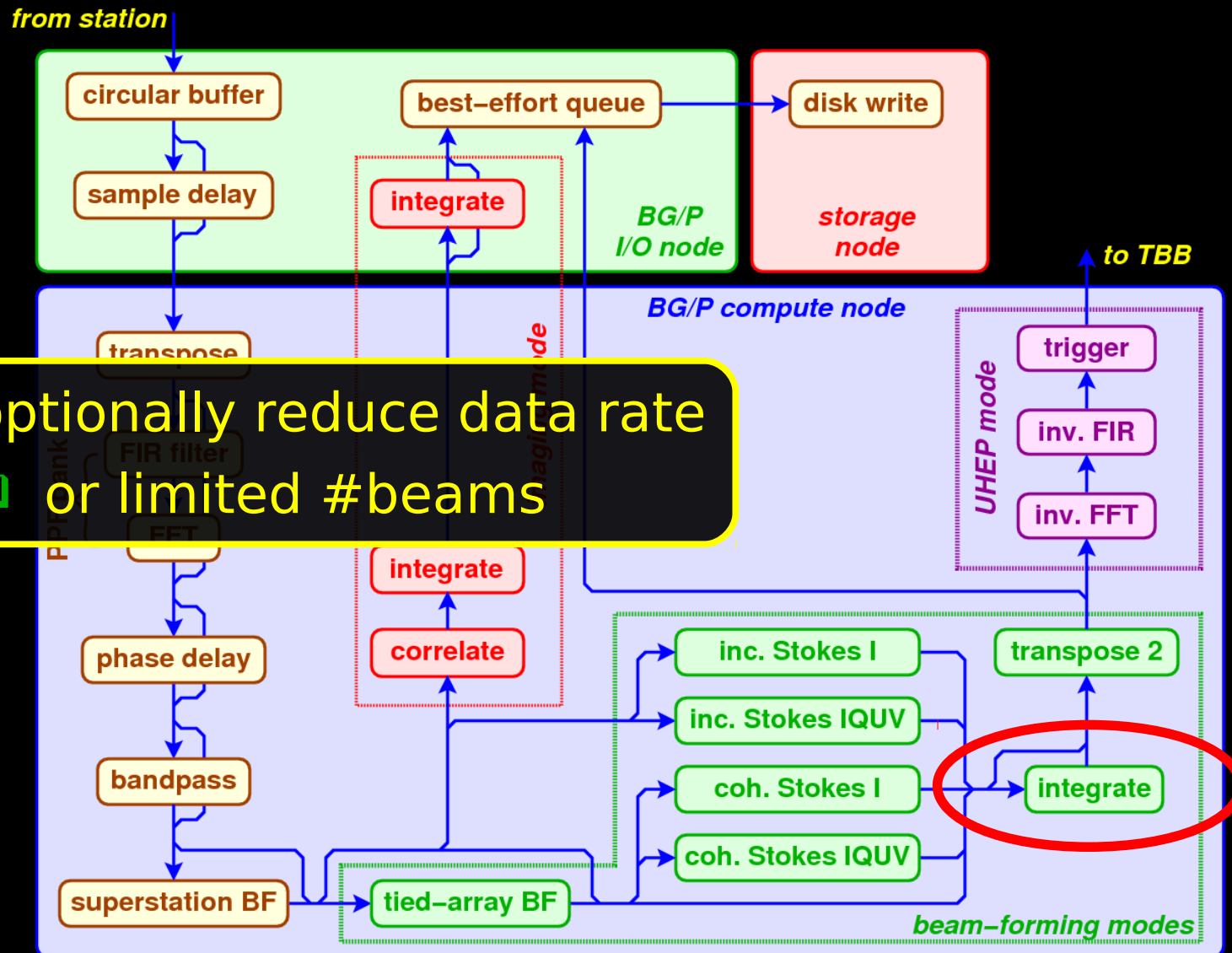
Coherent Beam Forming



Coherent Beam Forming

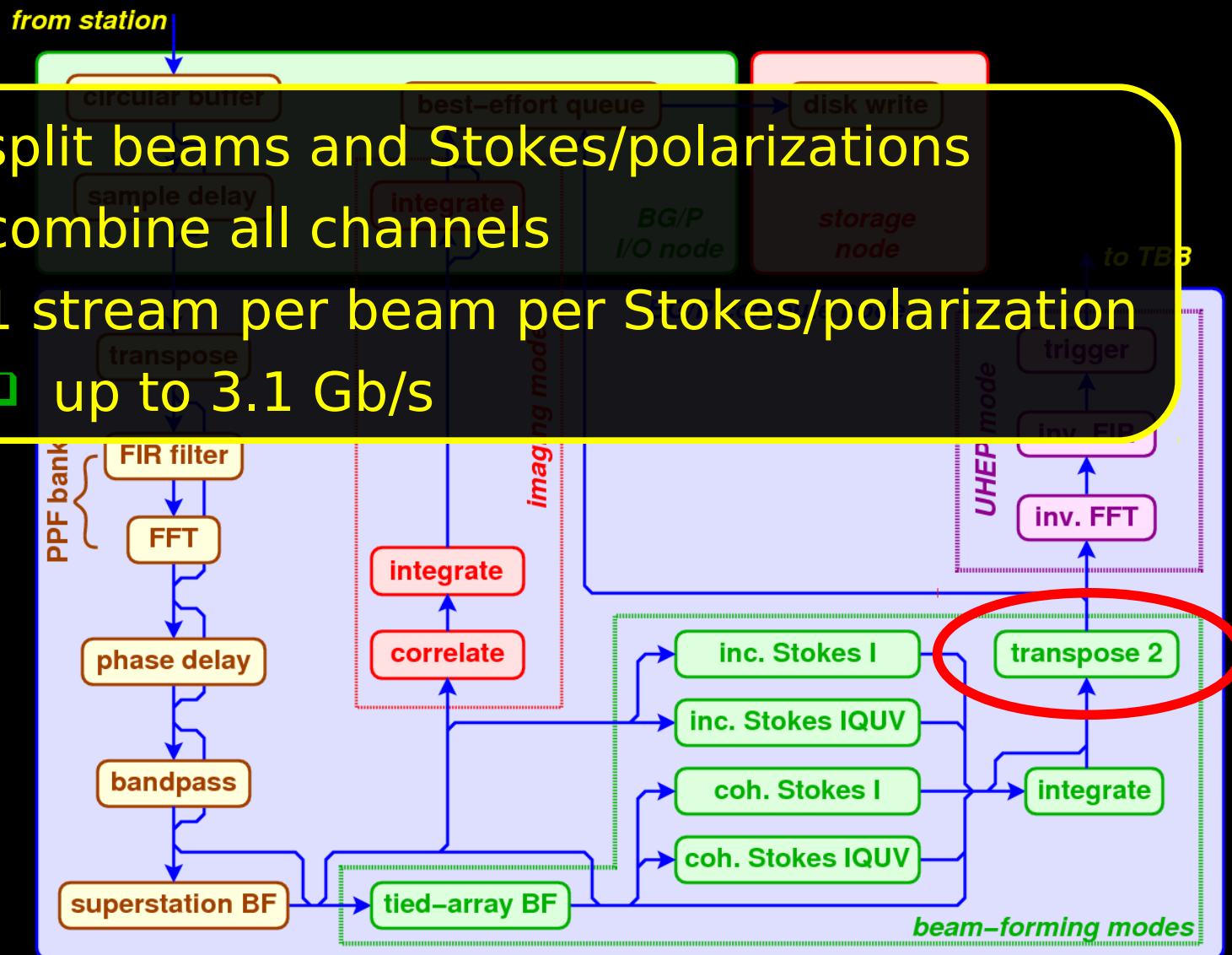


Integration

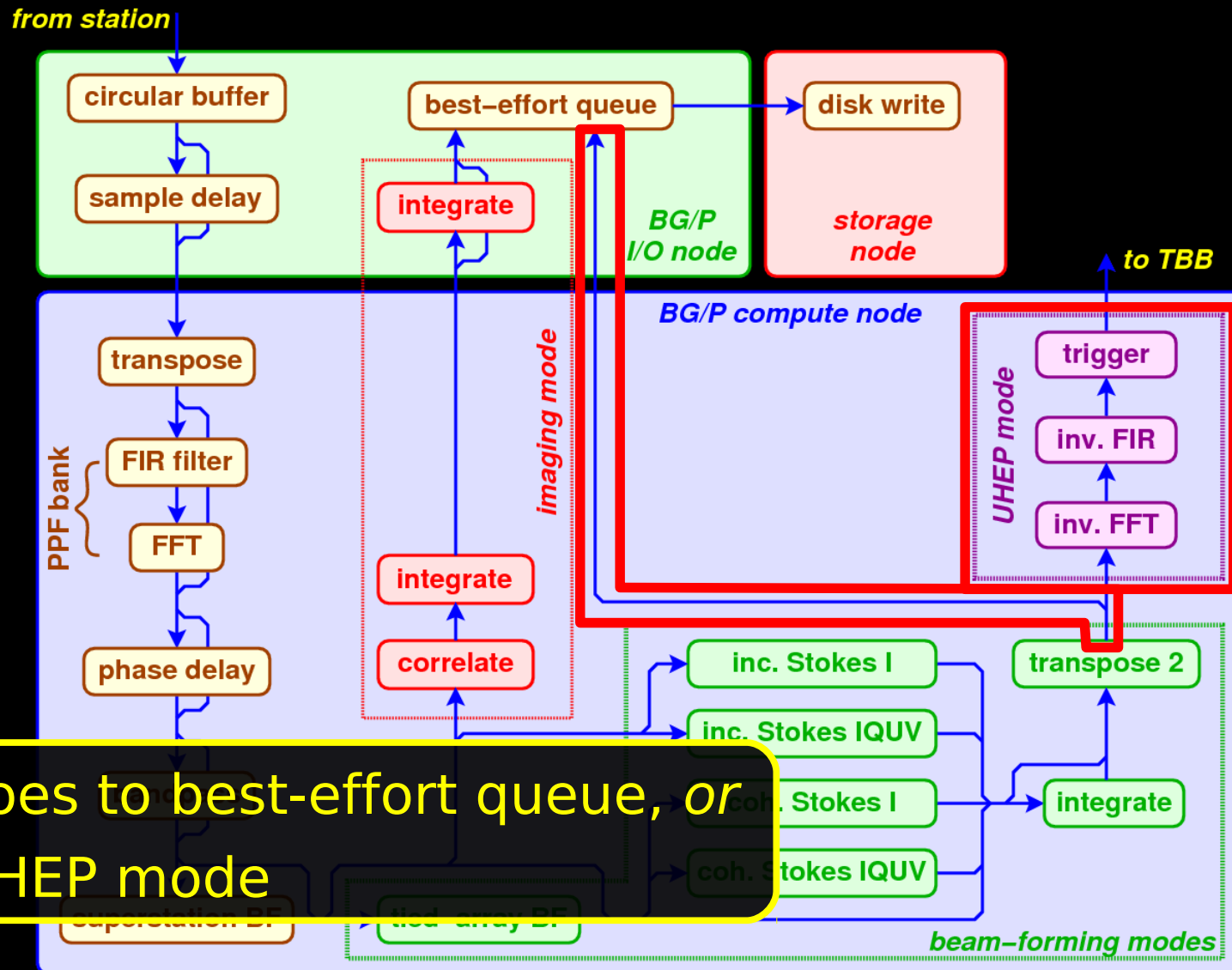


2nd Transpose

- ❑ split beams and Stokes/polarizations
- ❑ combine all channels
- ❑ 1 stream per beam per Stokes/polarization
- ❑ up to 3.1 Gb/s

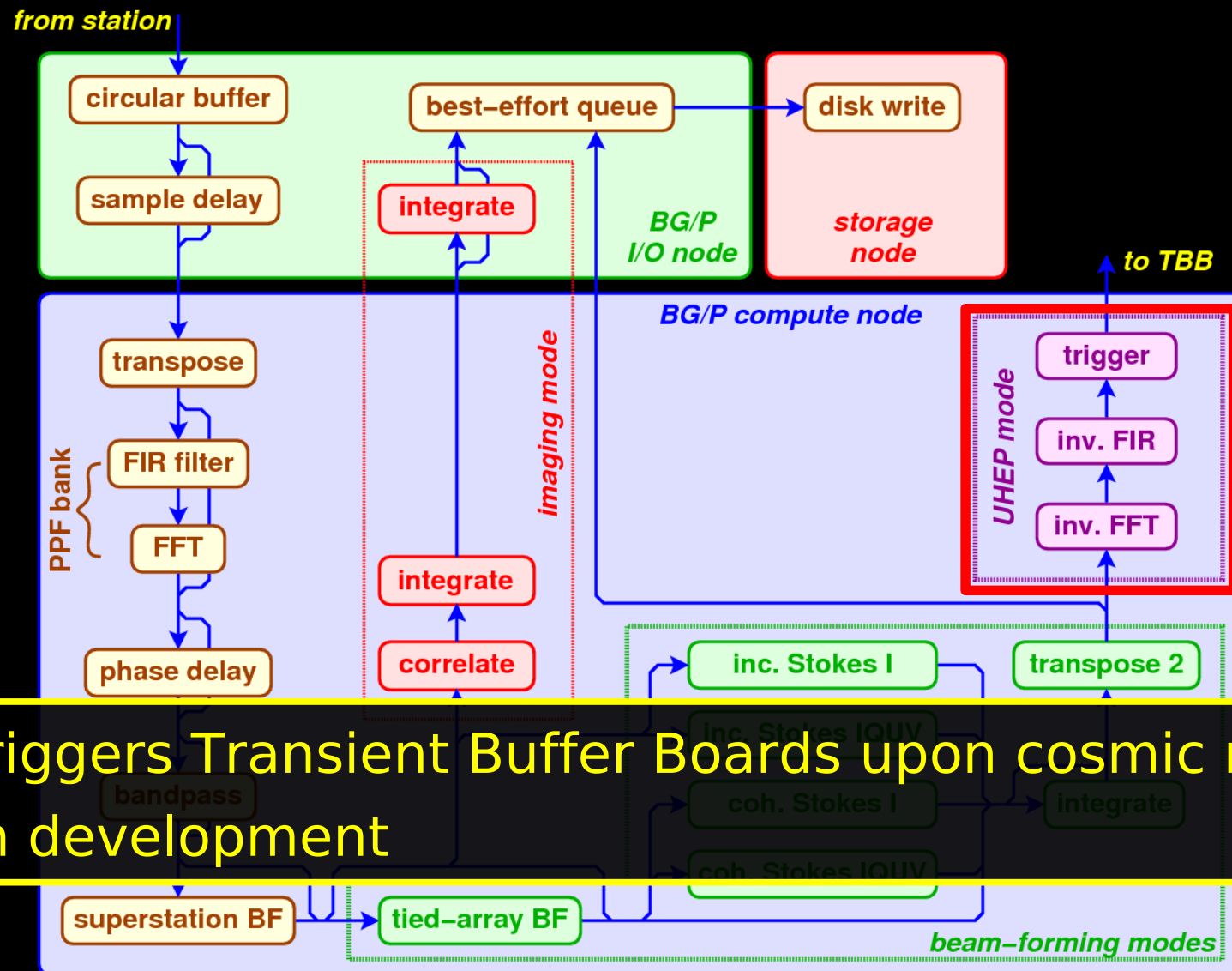


Beam Formed Data



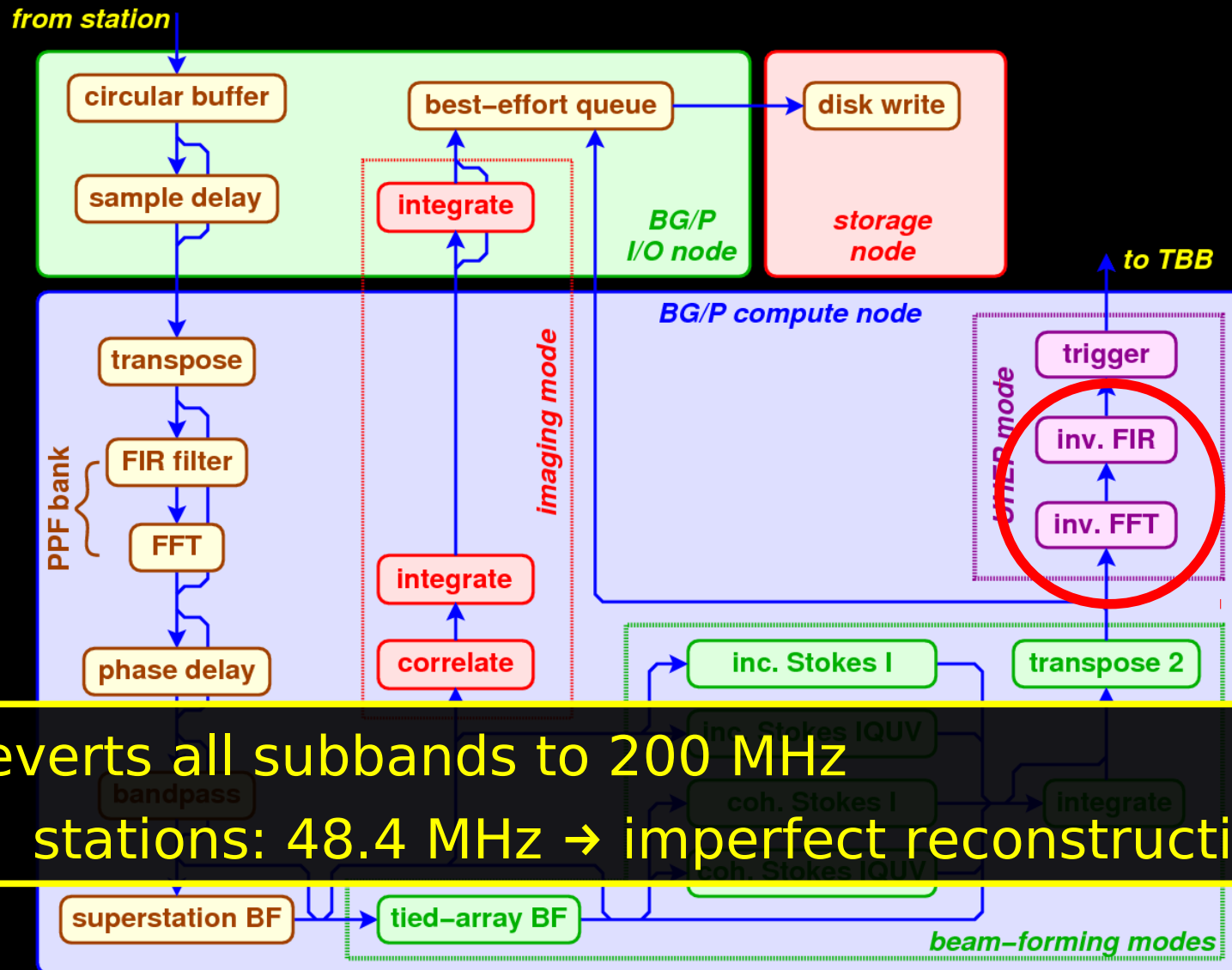
- ❑ goes to best-effort queue, or
- ❑ UHEP mode

Ultra-High Energy Particles Mode



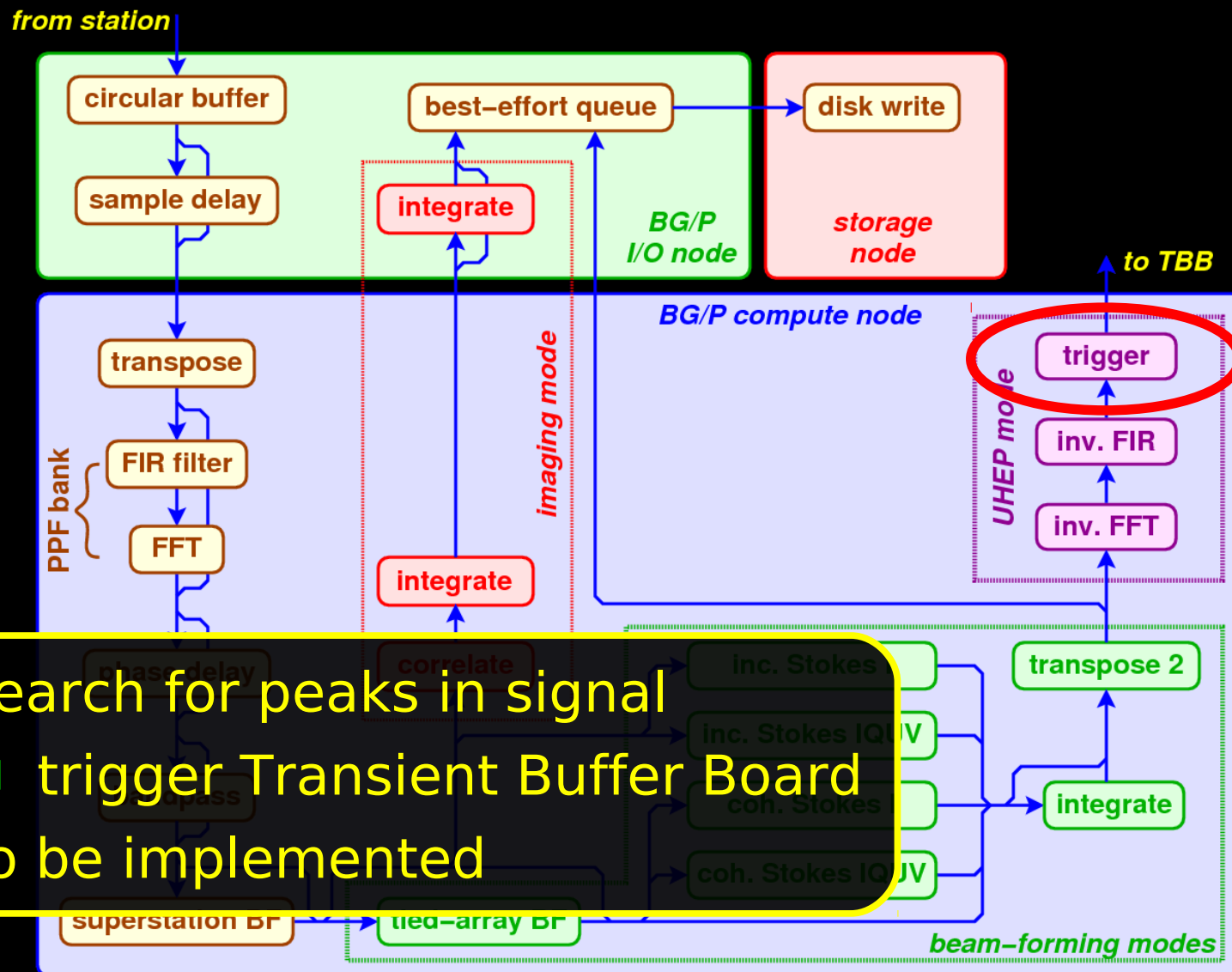
- ❑ triggers Transient Buffer Boards upon cosmic ray
- ❑ in development

Inverse PPF



- ❑ reverts all subbands to 200 MHz
- ❑ stations: 48.4 MHz → imperfect reconstruction

Trigger Algorithm



- ❑ search for peaks in signal
- ❑ trigger Transient Buffer Board
- ❑ to be implemented

Optimizations

- ❑ need high bandwidth, high performance, real-time behavior
 - ❑ use assembly (up to 96% of FPU peak)
 - ❑ developed optimized network protocol
 - ❑ modify OS
- ❑ >50% more BW than original specs
 - ❑ 48.4 MHz
 - ❑ increase efficiency of entire instrument

Flagging

- ❑ keep track of missing data
- ❑ no real-time flagger yet

Concurrent Observations

- multiple, independent observations
 - different stations, *or*
 - different subbands from same stations

observation	A	B	C	D
CS001	0 – 247			
CS002		0 – 18	19 – 120	121 – 247
CS003		0 – 18		121 – 247
CS004	0 – 247			
CS005		0 – 18	19 – 120	
CS006			19 – 120	121 – 247

Dynamic Observation Queue

- ❑ Blue Gene/P application “always” running
- ❑ dynamic observation queue
 - ❑ enter new obs
 - ❑ allows cancellations
- ❑ at obs start time:
 - ❑ activates compute nodes
 - ❑ spawns writers

Control

- ❑ python scripts
 - ❑ starts application
 - ❑ inserts observations
 - ❑ completes parameter set
 - ❑ used by developers
- ❑ Monitoring And Control
 - ❑ starts python scripts
 - ❑ monitors logs
 - ❑ used by observers

Characteristics

- ❑ correlator characteristics
 - ❑ beam forming characteristics not yet determined

bits/sample	16	8	4	
max #stations	64	64	48	
subbands	248	496	992	
beams * bandwidth	48.4	96.9	194	MHz
station data rate	3.1	3.1	3.1	Gb/s
total data rate in	200	200	150	Gb/s
total data rate out	36	72	81	Gb/s

Conclusions

- ❑ real-time central processing
 - ❑ flexible software
 - ❑ filter, correlate, beam form, ...
- ❑ Blue Gene/P
 - ❑ high performance
 - ❑ increased BW from 32 to 48.4 MHz