System z Flash Express

Introduction, Uses, and Benefits

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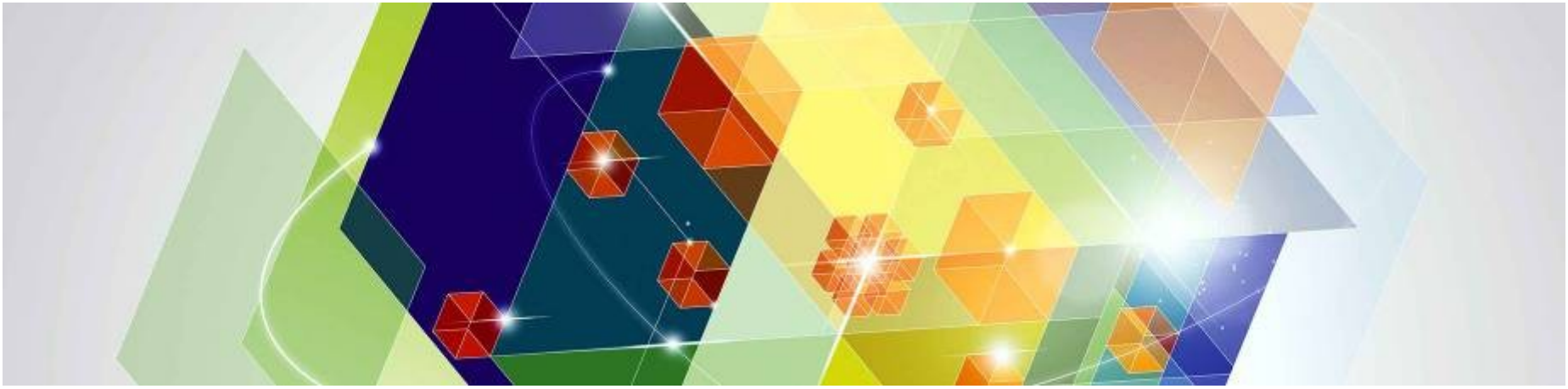
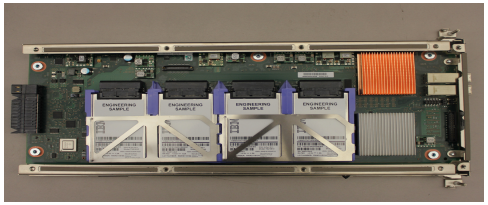


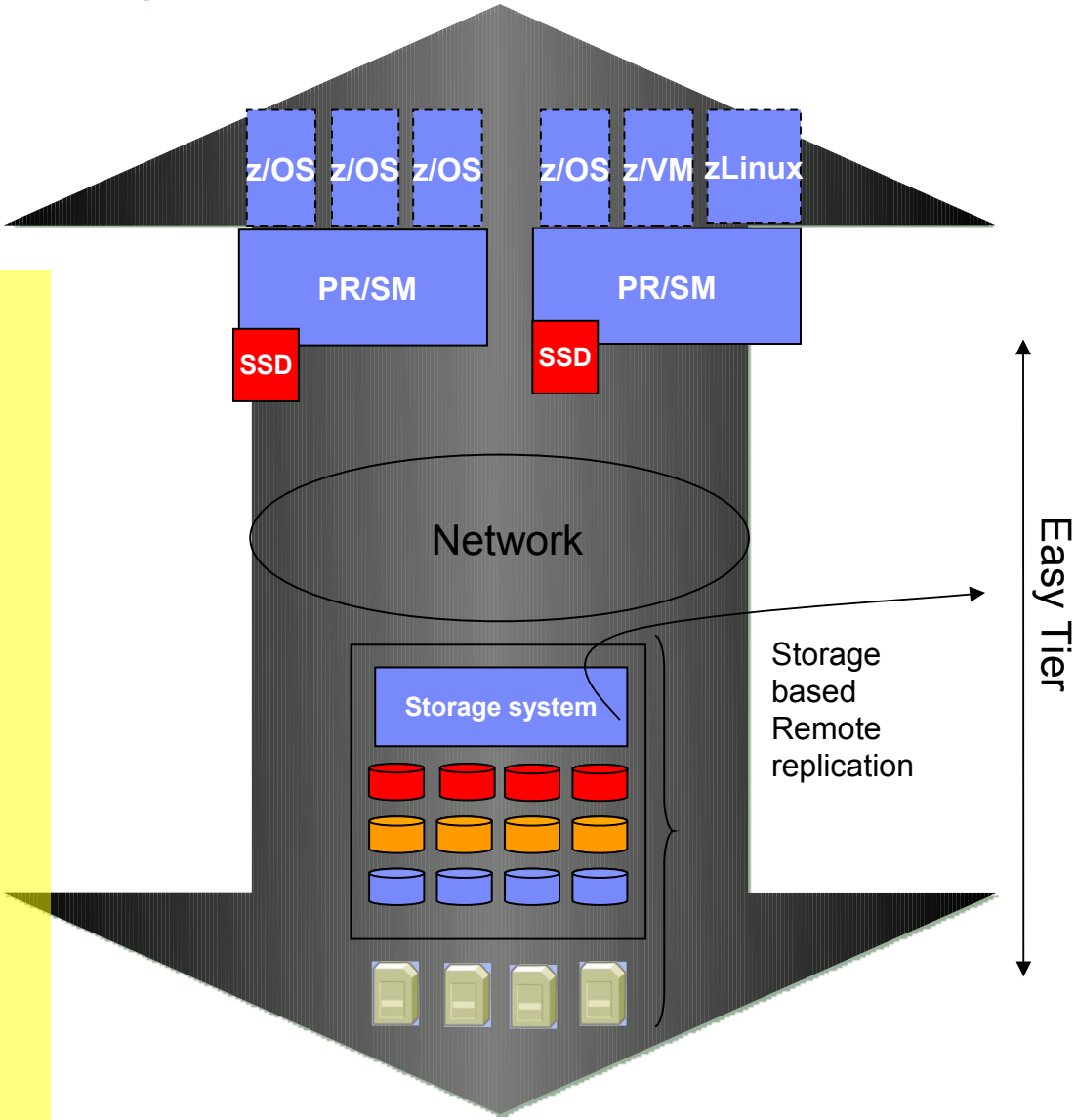
Agenda

- **z/OS Customer Value Proposition**
- **System z Flash Express and z/OS**
- **Flash Performance Results**
- **z/OS Flash Roadmap**
- **Under the Covers – Implementation Highlights**

System z Flash Express IO Adapter



- Flash Express is a PCIe IO adapter with NAND Flash SSDs (Solid State Drives)
- Flash Express is accessed using the Extended Asynchronous Data Mover
  - Optimized software path for Flash Access based on prior learning with z expanded store
- Flash Express provides continuous availability
  - RAID 10 to cover adapter failure
  - Concurrent Firmware update to cover service
- Flash Express is fully virtualized
  - A single adapter pair can provide Flash to 60 partitions on a CEC
  - Adapter RAS (call home, recovery, etc.) done at system level, not in OS.
  - Transparent migration to new adapter technology



IBM Flash Express – Smarter Availability for Smarter Systems

NEW

- **Flash Express is an innovative solution designed to help you compete effectively in today's marketplace**
  - Automatically improve availability for key workloads at critical processing times
  - Drive availability and performance for workloads that cannot tolerate paging spikes or inconsistent performance
  - Slash latency for critical application processing such as diagnostics collection
- **Extends IBM's expertise in memory management introducing a new tier of memory using Flash Express**
- **Provides a secured, resilient and immediately usable solution**
- **Planned Flash Express and pageable large page exploiters:**

  - z/OS V1.13 *Language Environment*
  -IMS 12 Common Queue Server
  -DB2 10 *
  - Java SDK601 SR4, and Java SDK7 SR3 and by extension:
  - *CICS Transaction Server 5.1*
  - WAS Liberty Profile v8.5
  - IMS 12
  - DB2

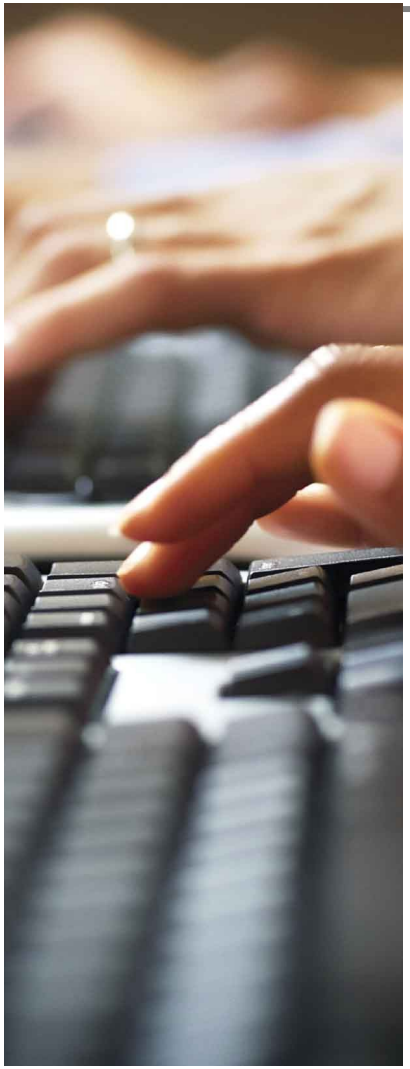
  Traditional WAS 8.0.0x and Traditional WAS 8.5.5 (future) **

**Traditional WAS support is planned for a future date
*DB2 date to be determined. Support for V10 with APARs is planned.

Flash Express Strengthens Availability

- Innovation to drive availability to exceptional levels
  - Extends IBM's expertise in memory management introducing a new tier of memory using Flash Express
  - Is an *industry unique* application of Flash to improve availability
  - Takes the next step in advanced memory management
- Flash Express can improve availability and reduce latency
  - Improves availability during transition periods and spikes
  - Helps accelerate start of day processing - batch to online
  - Enables faster snapshots of diagnostics (e.g. SVC dump, standalone dump)
  - With pageable large pages can improve performance of DB2 and Java
  - Ideal for applications with random read access and high read/write ratios
- Helps customers deliver vigorous service levels
  - Designed to help provide *exceptional* availability and fast response time
  - Delivered in tandem with pageable large pages for *superior* performance
- Minimal configuration- no special skills needed
  - Usable immediately; no special training required
  - Easy to set up and dynamically configurable

Representative Use Cases - Flash Express



Flash Express can reduce latency delays from paging to bring system availability to new heights and improve overall service levels

Application related errors will require collection of diagnostics. These diagnostics can be collected faster with Flash Express, reducing paging related delays that can impact your overall availability.

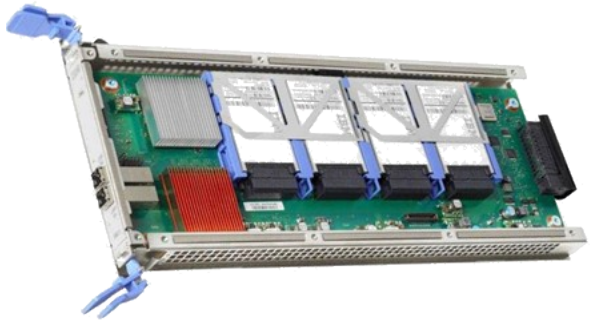
Having your working data resident in Flash can help accelerate start of day processing, and improve service for many industries at the busiest time of their work day- a time when they cannot afford disruptions.

DB2® and Java™ in memory buffer pools work to store and process application data. DB2 and Java can benefit from 1MB pageable large pages with Flash Express, improving overall performance.

Flash Express – What is it?

FLASH Express

- Flash Express is a PCIe IO adapter with NAND Flash SSDs
- Physically comprised of internal storage on Flash SSDs
- Used to deliver a new tier of memory- storage class memory
- Uses **PCIe I/O drawer**

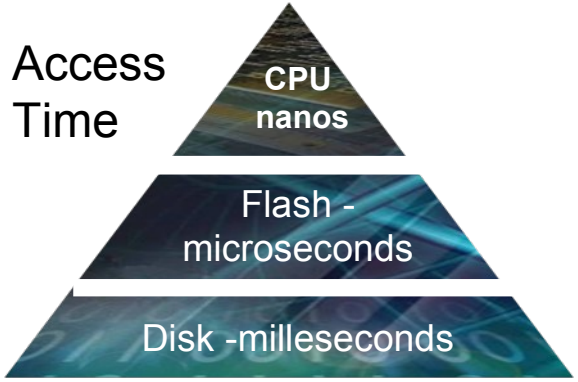


One Flash Express Card

- Sized to accommodate *all LPAR paging*
  - Each **card pair** provides **1.4 TB** usable storage (2.8 TB total)
  - Maximum 4 card pairs (4 X1.4=5.6 TB)

- Immediately usable
  - Simplifies capacity planning
  - No intelligent data placement needed
  - Full virtualization across partitions

- Robust design
  - Delivered as a **RAID10** mirrored pair
  - Designed for long life
  - Designed for concurrent firmware upgrade



Flash memory (SCM) blurs the distinction between memory and storage characteristics

- Secured
  - Flash Express adapter is protected with 128-bit AES encryption.
  - Key Management provided based on a Smart Card
  - Secure Cryptographic Erase meets audit requirements

IBM Flash Express – Smarter Availability for Smarter Systems

Outstanding Availability and Performance - Innovative Flash Express

- Companies competing for the highest quality of service in today's market must deliver **outstanding** availability and performance
- Changes in workload processing can impact service levels at critical processing times

- **Flash Express is an innovative solution designed to help you improve availability and performance to compete effectively in today's market**
  - Automatically improves availability for key workloads at critical processing times
  - Drives availability and performance for workloads that cannot tolerate paging spikes or inconsistent performance
  - Slashes latency for critical application processing such as start of day processing and also collection of diagnostics (SVC dumps, standalone dumps)
  - Delivered as a new adapter card in the PCIe I/O drawer

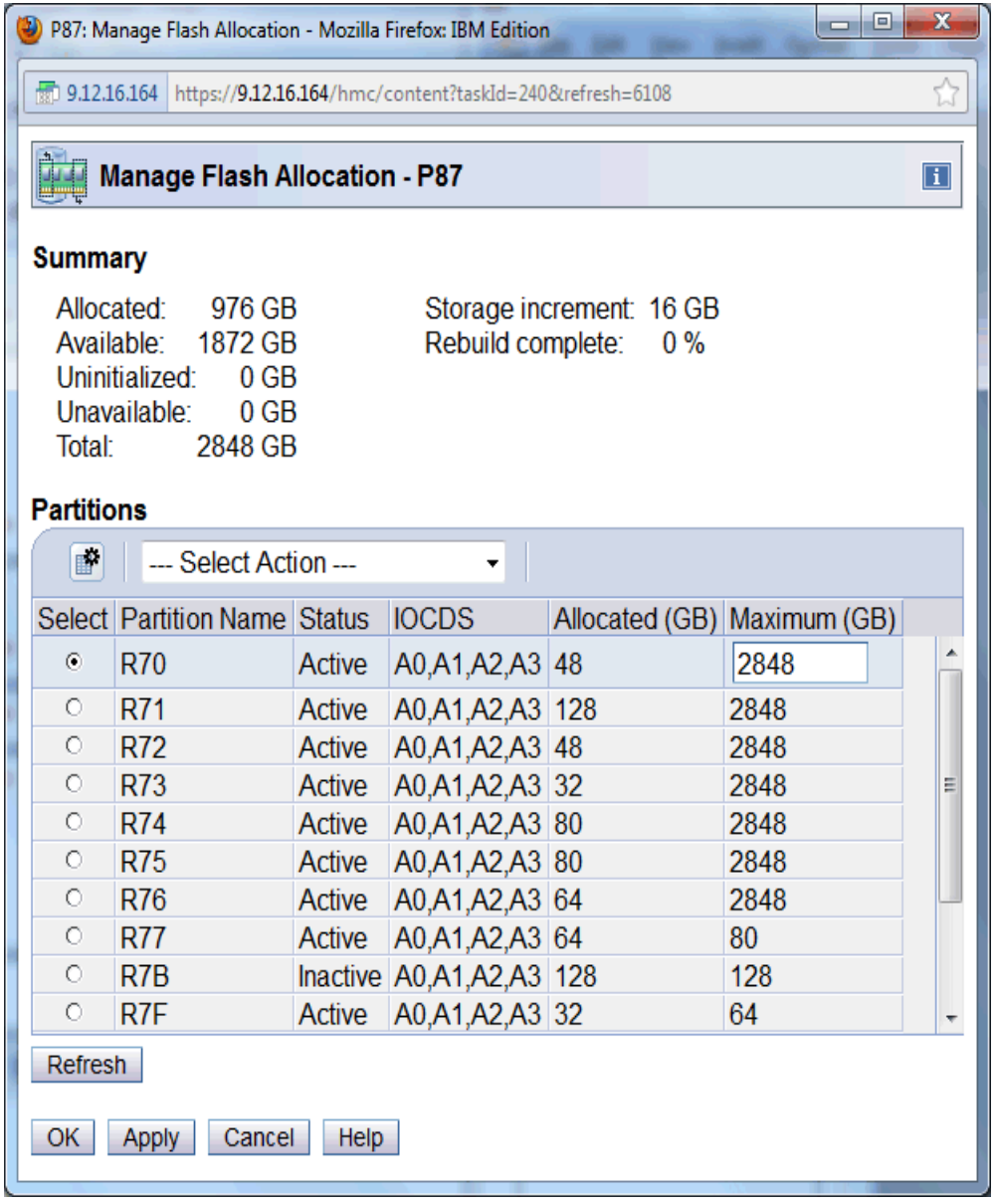
- **Benefits**
  - Improves availability and performance helping companies achieve highest service levels
  - Delivers a secured, resilient and immediately usable solution
  - Automatic, requires minimal setup, no special training needed

System z Flash and z/OS

Allocating z FLASH

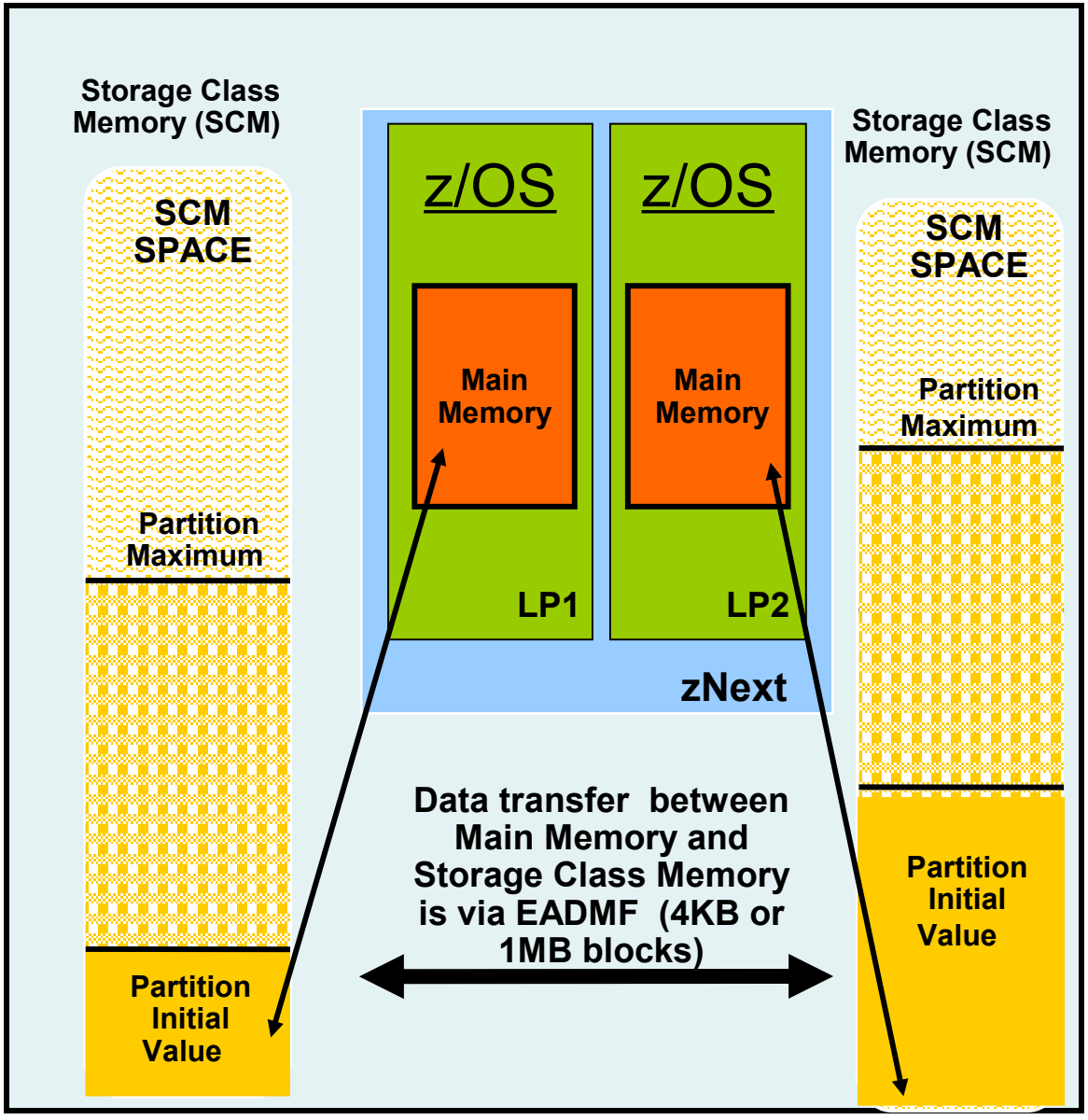
Allocating Flash to a partition

- The initial and maximum amount of Flash Memory available to a particular logical partition is specified at the SE or HMC via a new Flash Memory Allocation panel
- Can dynamically change maximum amount of Flash Memory available to a logical partition
- Additional Flash Memory (up to the maximum allowed) can be configured online to a logical partition dynamically at the SE or HMC
  - For z/OS this can also be done via an operator command
- Can dynamically configure Flash Memory offline to a logical partition at the SE or HMC
  - For z/OS this can also be done via an operator command
- Predefined subchannels, no IOCDS



z FLASH Virtualization

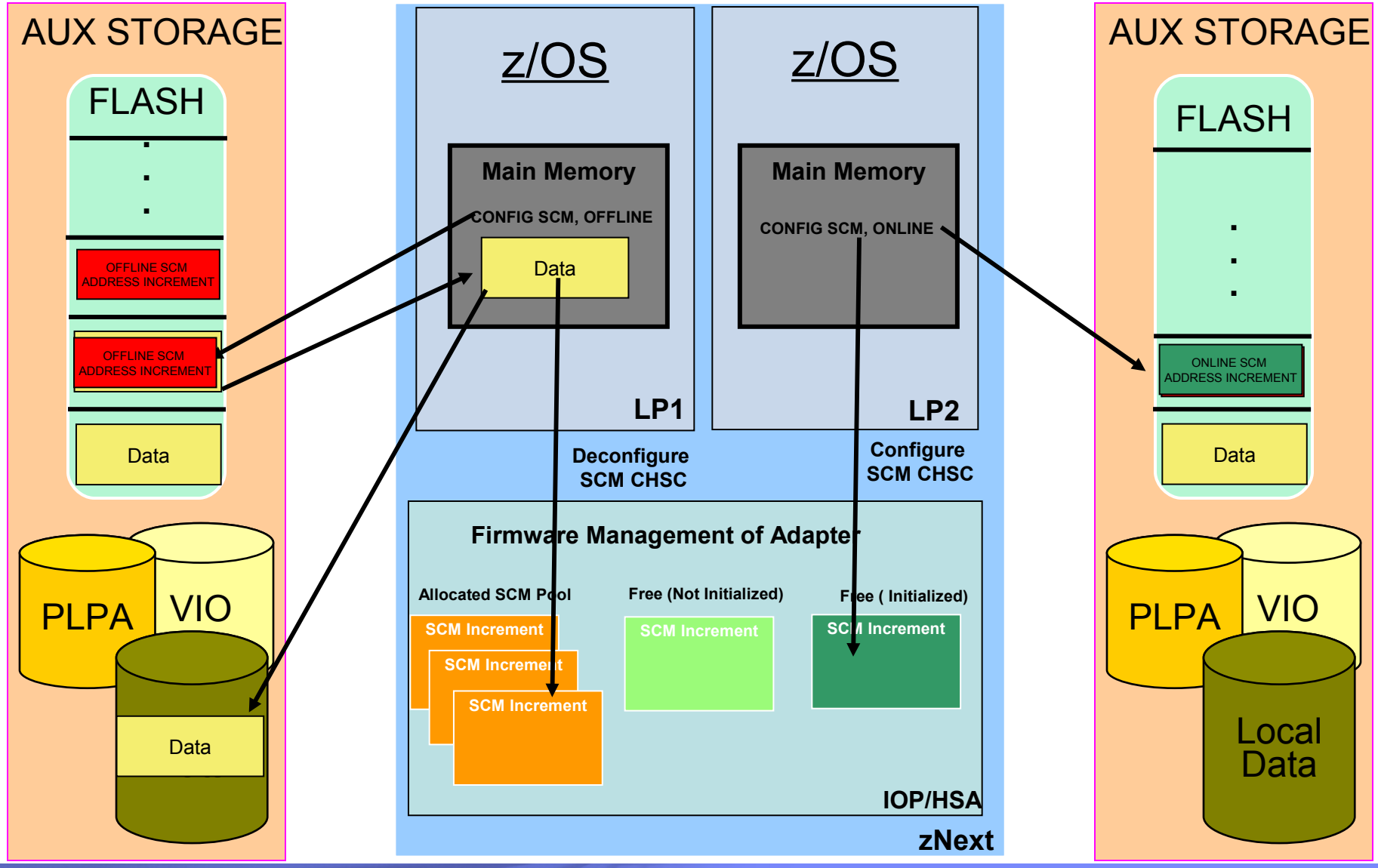
- **Full virtualization of physical Flash PCIe cards across partitions, software sees an Abstracted Flash Storage Space…**
  - Allows each logical partition to be configured with its own SCM address space
  - Allocate Flash to partitions by amount, not card size
  - Ability to change underlying technology while preserving API
- ► **No Hardware Specifics in Software.**
  - Error Isolation, Transparent mirroring, Centralized diagnostics, etc.
  - Hardware Logging, FRU Call, Recovery: Independent of software



FLASH for z/OS Paging Value

- **Flash Memory is a faster paging device as compared to HDD**
  - The value is NOT in replacing memory with Flash but replacing disk with Flash
  - Flash is suitable for workloads that can tolerate paging and will not benefit workloads that cannot afford to page
  - The z/OS design for Flash Memory does not completely remove the virtual storage constraints created by a paging spike in the system. (Some scalability relief is expected due to faster paging I/O with Flash Memory.)

A z/OS Flash Configuration



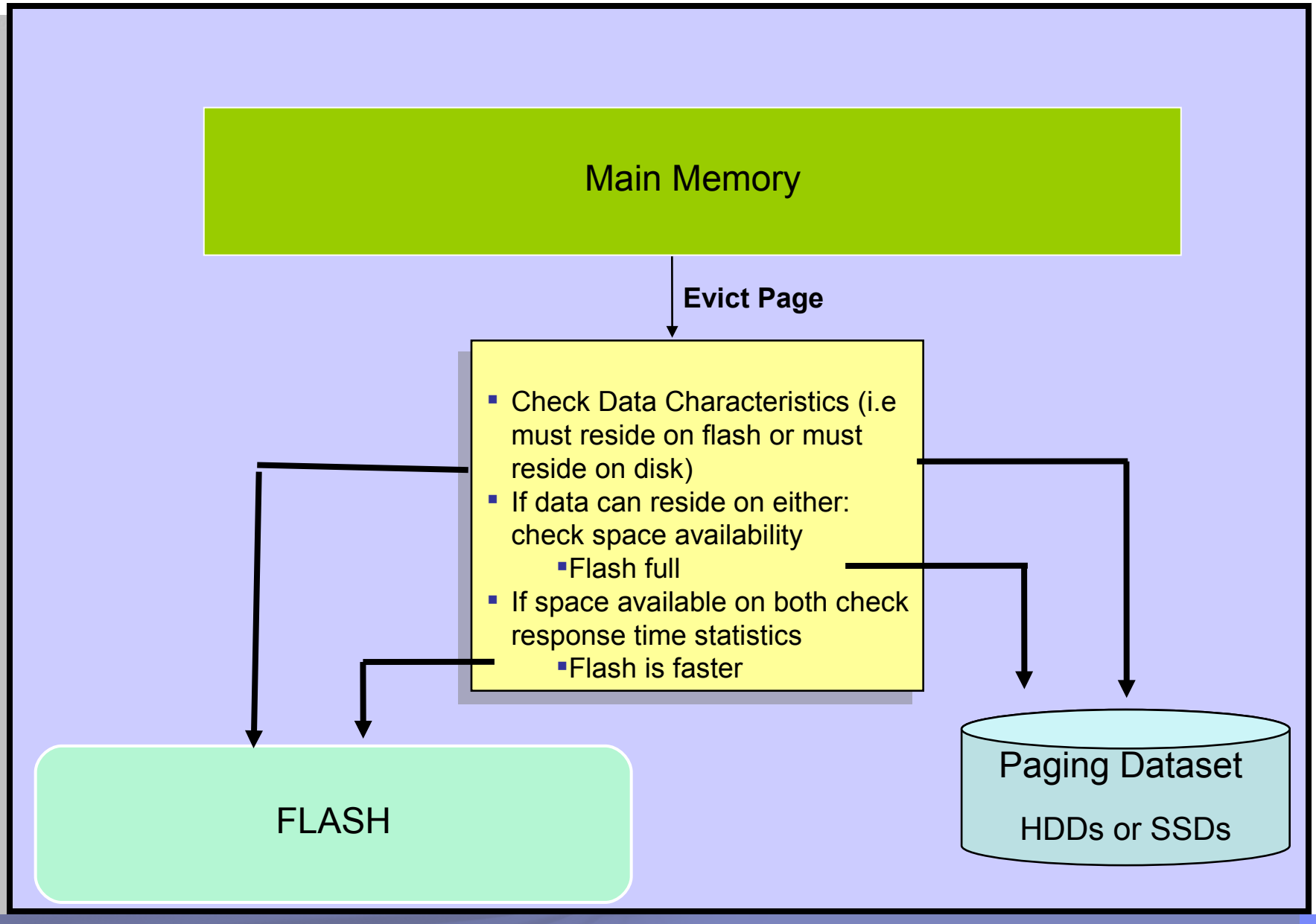
Typical Customer Configurations for FLASH

- **Flash card pair memory size is 1.4TB**
  - Min: 1 Card Pair
  - Max: 4 Card Pairs

- **Typical customer configuration is 6 to 8 LPARs per CEC and 40GB - 80GB for paging configuration dataset size**

- **Even with 10 LPARs per CEC, each LPAR has 140 GB of Flash Memory available for its paging datasets, more than double the current typical customer configuration.**
  - All paging data can easily reside on Flash
  - Data will preferably go to Flash and only go to disk (if any) when Flash is full
  - No intelligent placement of data on internal Flash needed

Flash vs Disk Placement Criteria



Flash vs Disk Placement Criteria

Data Type	Data Page Placement
PLPA	At IPL/NIP time PLPA pages will be placed both on Flash and disk.
VIO	VIO data will always be placed on disk (First to VIO accepting datasets with any spillover flowing to non-vio datasets)
Pageable Large Pages	If contiguous Flash space is available, pageable large page will be written to Flash. If Flash is not available in the system configuration pageable large pages will be backed with 4k page frames.
All other data	If available space exists on both Flash and disk then make a selection based on response time.

z/OS FLASH Use Cases

- Paging
  - **z/OS paging subsystem will work with mix of internal Flash and External Disk**
    - –Self Tuning based on measured performance
    - –Improved Paging Performance, Simplified Configuration
  - **Begin Paging 1 MB Large Pages only on Flash**
    - –Exploit Flash's random IO read rate to get CPU performance by enabling additional use of Large Pages. Currently large pages are not pagable.
  - **Begin Speculative Page-In of 4K Pages, 1MB Pages only on Flash**
    - –Exploit Flash's random IO read rate to get Improved Resilience over Disruptions.
    - –Market Open, Workload Failover

Flash Memory Usage and Invocation

- **New PAGESCM= keyword in IEASYSxx defines the amount of flash to be reserved for paging**
  - **Value may be specified in units of M, G, or T**
  - **NONE indicates do not use flash for paging**
  - **ALL (default) indicates all flash defined to the partition is available for paging**

Flash Memory Usage and Invocation (cont)…

- **New messages issued during IPL indicate the status of SCM**
  - `IAR031I USE OF STORAGE-CLASS MEMORY FOR PAGING IS ENABLED -PAGESCM=ALL, ONLINE=00065536M`

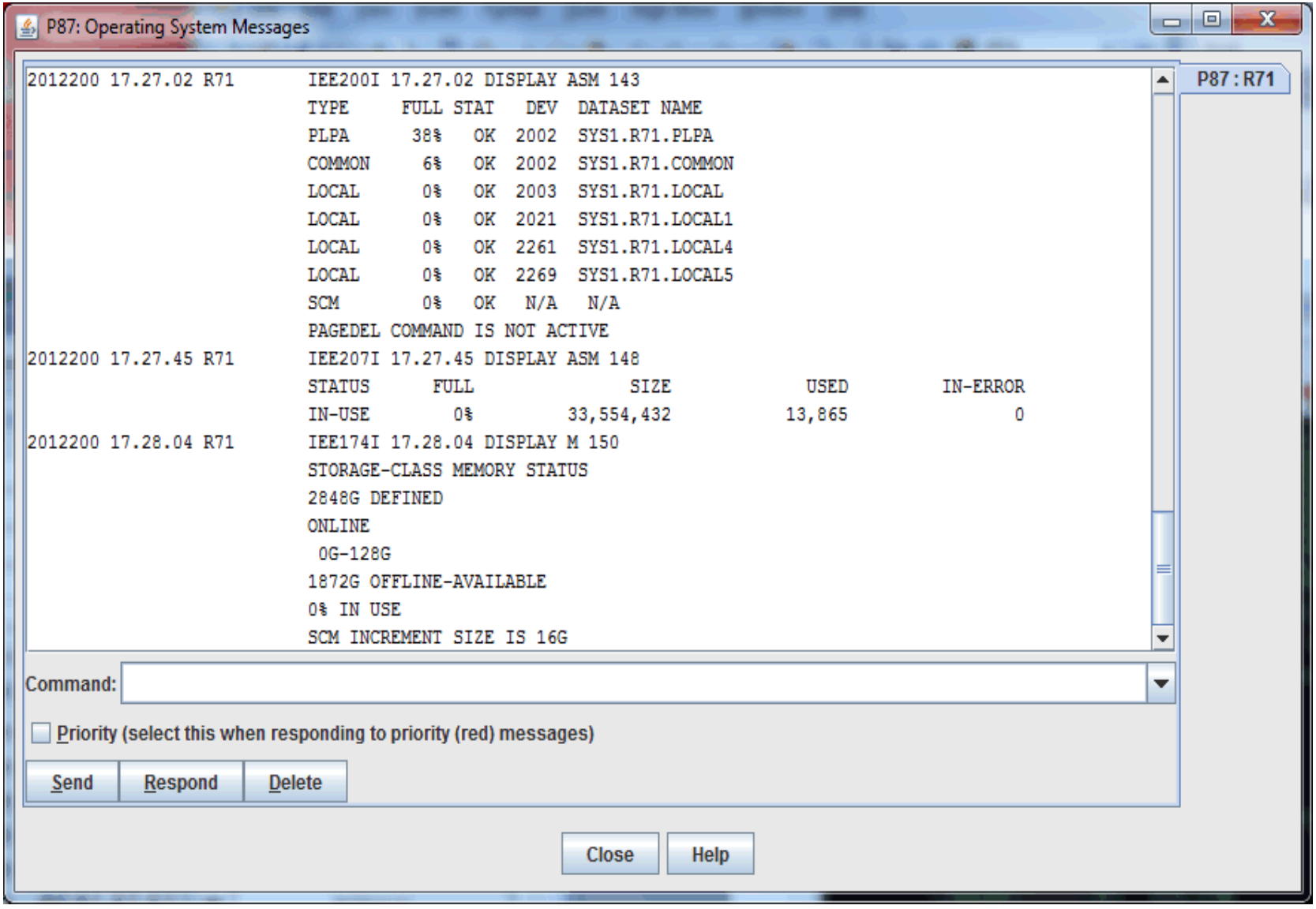
  OR

  - `IAR032I USE OF STORAGE-CLASS MEMORY FOR PAGING IS NOT ENABLED – PAGESCM=NONE`

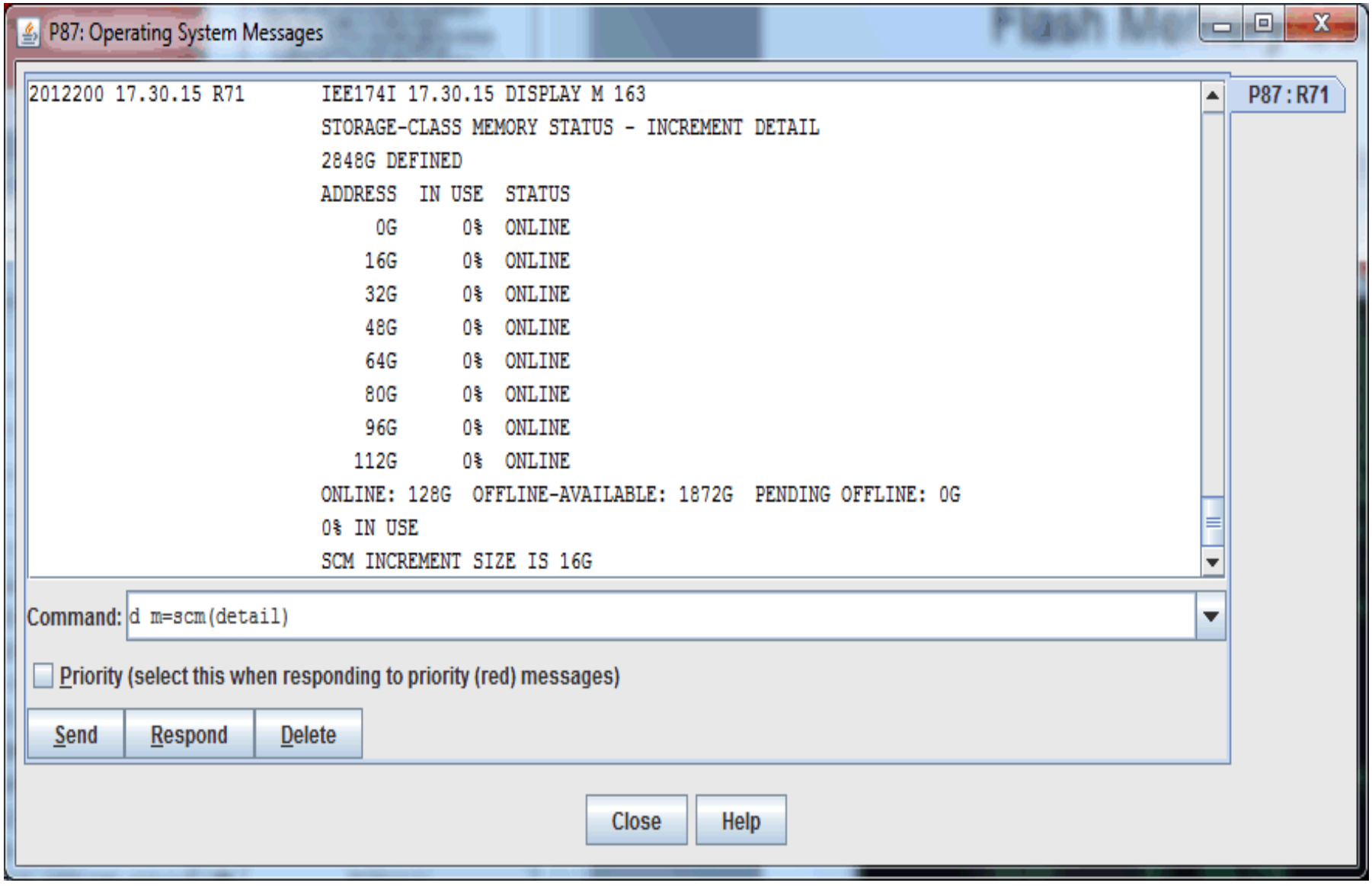
Flash Memory Usage and Invocation (cont)…

- **The D ASM and D M commands are enhanced to display flash-related information/status**
  - **D ASM lists SCM status along with paging data set status**
  - **D ASM,SCM displays summary of SCM usage**
  - **D M=SCM display SCM online/offline and increment information**
  - **D M=SCM(DETAIL) displays detailed increment-level information**
- **The CONFIG ONLINE command is enhanced to allow bringing additional SCM online**
  - **CF SCM(amount),ONLINE**

Flash Memory Usage and Invocation (cont)…



Flash Memory Usage and Invocation (cont)…



Display ASM Command

d asm

```
IEE200I 17.17.46 DISPLAY ASM 944
TYPE      FULL STAT    DEV  DATASET NAME
PLPA      100% FULL   02E6  SYS1.PLPA.PAGCOM
COMMON     61%   OK   02E6  SYS1.COMMON.PAGCOM
LOCAL       0%   OK   098E  SYS1.LOCAL.PAGEP2
LOCAL       0%   OK   0987  SYS1.LOCAL.PAGEP3
LOCAL       0%   OK   098F  SYS1.LOCAL.PAGEP4
SCM        11%   OK    N/A   N/A
```

d asm,scm

```
IEE207I 17.35.02 DISPLAY ASM 947

STATUS       FULL      SIZE              USED          IN-ERROR
IN-USE        11%    16,777,216        2,096,144          0
```

Flash Related Commands

D M=SCM

```
IEE174I 17.57.26 DISPLAY M 230
STORAGE-CLASS MEMORY STATUS
80G DEFINED
ONLINE
 0G-64G
16G OFFLINE-AVAILABLE
14% IN USE
SCM INCREMENT SIZE IS 16G
```

D M=SCM(DETAIL)

```
IEE174I 17.57.30 DISPLAY M 232
STORAGE-CLASS MEMORY STATUS - INCREMENT DETAIL
80G DEFINED
ADDRESS  IN USE  STATUS
    0G     55%  ONLINE
   16G      0%  ONLINE
   32G      0%  ONLINE
   48G      0%  ONLINE
ONLINE: 64G  OFFLINE-AVAILABLE: 16G  PENDING OFFLINE: 0G
14% IN USE
SCM INCREMENT SIZE IS 16G
```

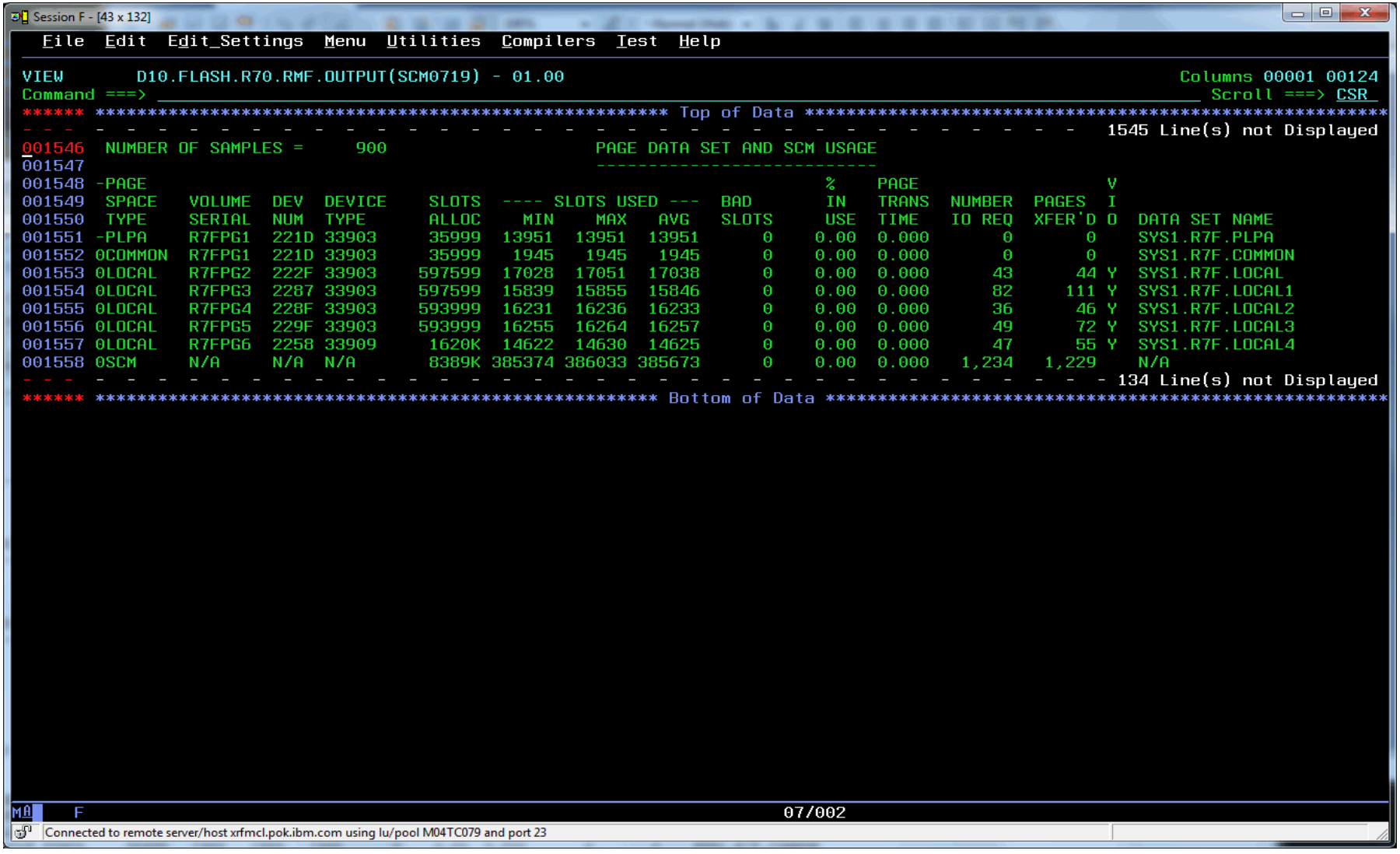
CF SCM(16G),ONLINE

```
IEE195I SCM LOCATIONS 64G TO 80G ONLINE
IEE712I CONFIG   PROCESSING COMPLETE
```

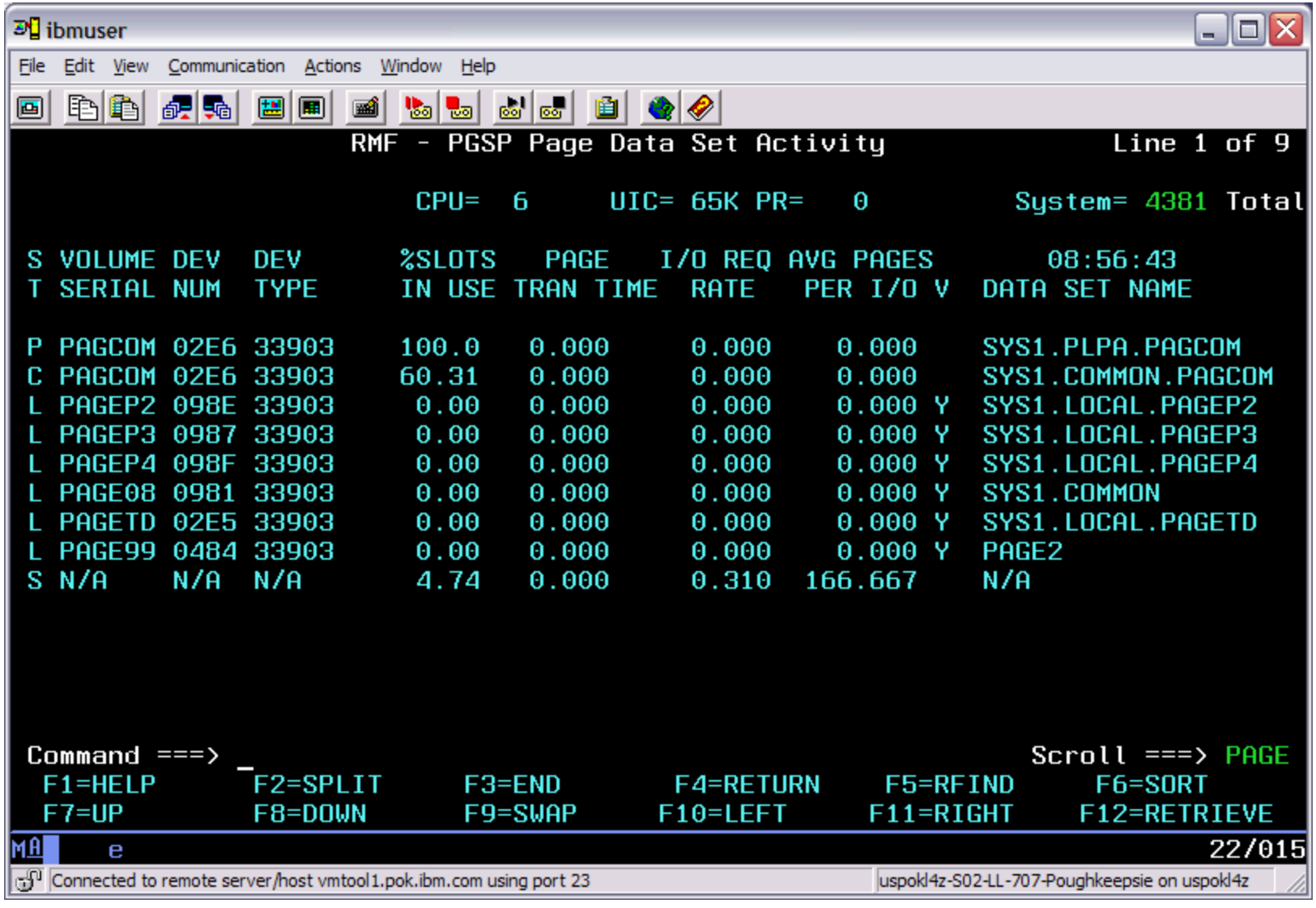
RMF Paging Activity Report

```
Session F - [43 x 132]
 File  Edit  Edit_Settings  Menu  Utilities  Compilers  Test  Help

VIEW       D10.FLASH.R70.RMF.OUTPUT(SCM0719) - 01.00                              Columns 00001 00124
Command ===>                                                                          Scroll ===> CSR
****** ******************************************************* Top of Data *************************************************
- - -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  1514 Line(s) not Displayed
001515 1                                                  P A G I N G   A C T I V I T Y
001516
001517             z/OS V1R13              SYSTEM ID R7F             DATE 07/19/2012            INTERVAL 15.00.000
001518                                     RPT VERSION V1R13 RMF      TIME 16.00.00              CYCLE 1.000 SECONDS
001519 -OPT = IEAOPTRD   LFAREA SIZE =  2147484K   MEMORY OBJECTS AND HIGH VIRTUAL STORAGE FRAMES
001520  -----------------------------------------------------------------------------------------------------------
001521 0MEMORY OBJECTS         COMMON     SHARED       1 MB
001522  ------------------  ---------  ---------  ---------
001523        MIN                 65          0          4
001524        MAX                 65          0          4
001525        AVG                 65          0          4
001526 01 MB FRAMES          ------------ FIXED ------------  ----------- PAGEABLE ----------
001527  ------------------     TOTAL  AVAILABLE     IN-USE       TOTAL  AVAILABLE     IN-USE
001528        MIN              2,048      1,874        174       1,045        799        246
001529        MAX              2,048      1,874        174       1,045        799        246
001530        AVG              2,048      1,874        174       1,045        799        246
001531 0HIGH SHARED FRAMES     TOTAL     CENTRAL STORAGE                   AUX DASD    AUX SCM
001532  ------------------  ---------     ---------------                 ---------  ---------
001533        MIN          136902.1M               1,295                         0          0
001534        MAX          136902.1M               1,295                         0          0
001535        AVG          136902.1M               1,295                         0          0
001536 0HIGH COMMON FRAMES     TOTAL     CENTRAL STORAGE    FIXED 4K      AUX DASD    AUX SCM
001537  ------------------  ---------     ---------------  ---------     ---------  ---------
001538        MIN           17301504             257,190  3,194,870      258,137    438,688
001539        MAX           17301504             257,190  3,194,870      258,137    438,688
001540        AVG           17301504             257,190  3,194,870      258,137    438,688
- - -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  - 152 Line(s) not Displayed
****** ****************************************************** Bottom of Data ***********************************************

MA    F                                                     04/015
Connected to remote server/host xrfmcl.pok.ibm.com using lu/pool M04TC079 and port 23
```

RMF Paging Activity Report (cont)…



RMF Monitor II – Page Data Set Activity



SVC Dump Statistics

- VERBX IEAVTSFS
- Shows total dump capture time, system/task non-dispatch time, page operations required to dump requested address space (real-to-real copies, page-ins, etc)

SVC Dump Statistics (cont)

Dump start	10/09/2012 14:30:29.867495
Dump end	10/09/2012 14:30:44.224584
Total dump capture time	**00:00:14.357089**
System nondispatchability start	10/09/2012 14:30:29.870030
System set nondispatchable	10/09/2012 14:30:29.870048
Time to become nondispatchable	00:00:00.000017

SVC Dump Statistics (cont)

```
Asid 0071:
  Local storage start              10/09/2012 14:30:30.424083
  Local storage end                10/09/2012 14:30:43.011936
  Local storage capture time       00:00:12.587853
  Tasks reset dispatchable         10/09/2012 14:30:43.011944
  Tasks were nondispatchable       00:00:12.587861

  Defers for frame availability              0
  Pages requiring input I/O             170196
  Source page copied to target           16987
  Source frames re-assigned             566614

  Source AUX slot IDs re-assigned        15749
```

Flash Express Performance Results

- **All performance information was determined in a controlled environment.**
- **Actual results may vary.**
- **Performance information is provided “AS IS” and no warranties or guarantees are expressed or implied by IBM.**

Flash Express Performance Test Setup

- z/OS Tests were designed to demonstrate flash performance under paging workloads that are typically encountered in a z/OS enterprise environment
  - SSD performance is not only about the number of IOPS but about steady performance over time and consistent latency
    - **Preconditioned SSDs** with random-write IO engage the device's wear leveling, error handling, and flash management algorithms
  - Comparison DASD Characteristics used **current device configurations**
    - DS8800 model 2107-951
    - 60 GB cache, cache hit rates of 95-100% were observed during the tests
    - DASD was not shared with any other systems and did not have any I/O traffic other than the paging traffic used for these tests
    - Configured 16 local page datasets spread across 8 LCUs

Flash Express Performance Benefits

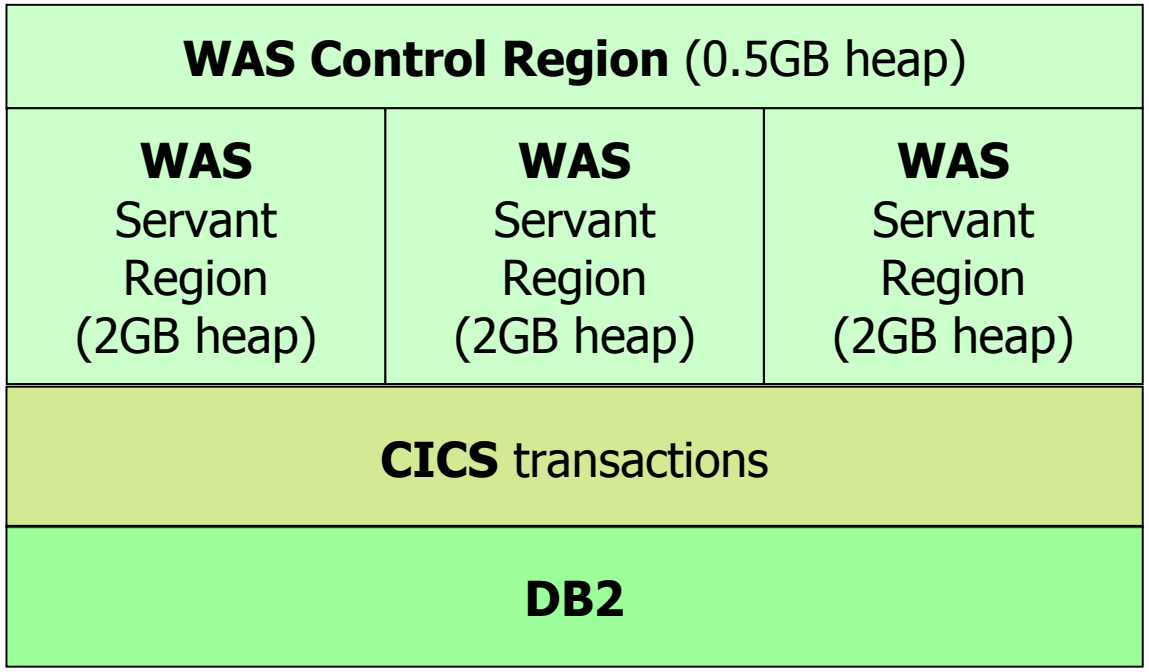
Test Results

- FLASH paging benefits
  - Improved availability through faster paging at critical times
    - Faster workload transitions (e.g.; morning startup)
      - *meaning less time to reach peak transaction rates*
    - Faster SVC dumps (reduced **non-dispatchable** time)
      - *meaning higher availability – more transactions can be run*
- Pageable Large Page benefit
  - Java realizes performance benefits from use of large 1MB pageable pages
    - Large pages benefits for JIT Code Cache, 31 bit Java applications
    - No authorization needed to access fixed large pages
    - Approximately 5-8% CPU improvement from PLP

Workload Configuration Block Diagram

Building block – A WAS instance accessing CICS and DB2

Each WAS instance has a WAS Control Region and 3 WAS Servant Regions.
Each WAS Control Region has a 0.5GB heap plus a JIT Code cache.
Each WAS Servant Region has a 2GB heap plus a JIT Code Cache.



2-book zEC12

Test Configuration

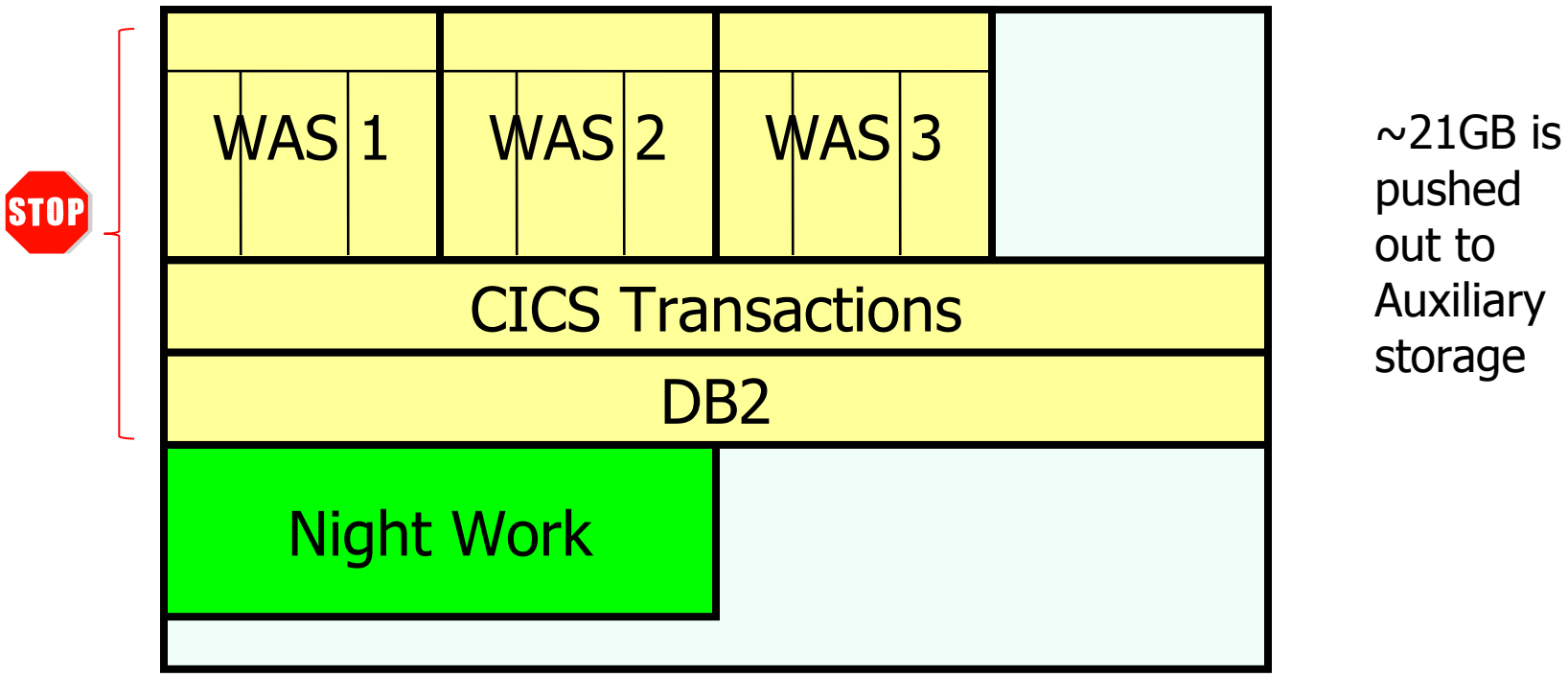
- WAS 7 (3 servants each with two GB heap) + 1 control region (.5 GB Heap)
- CICS V4.2, DB210 on a zEC12
- Storage: DS8800 2107-951 with 60GB cache, very fast device
- Tests simulated morning transition time typical of trading or call center work
- SVC dump measurements were taken for an 18 GB dump.

I. Morning Transition

Transition from night batch to OLTP

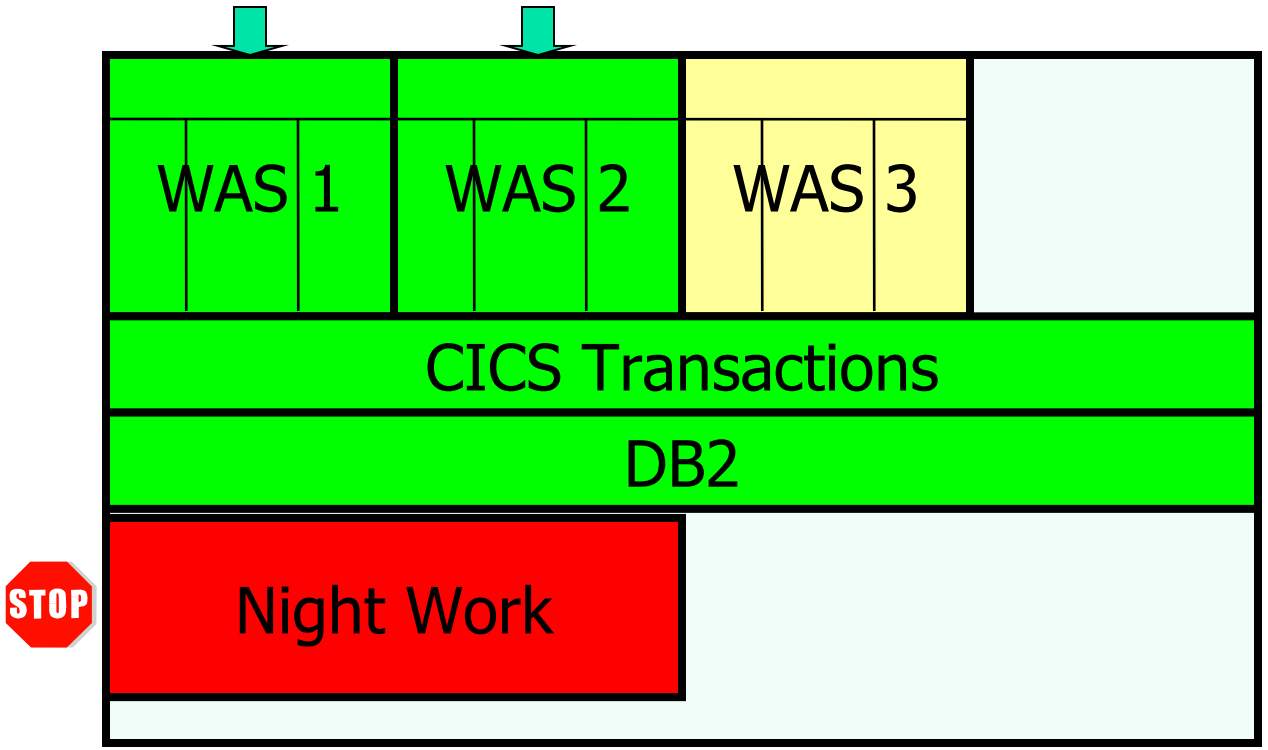
WAS workload to CICS and DB2 represents OLTP work which is then stopped

Simulated overnight work consumes real storage pushing other pages out



Morning Transition - Transition from night batch to OLTP

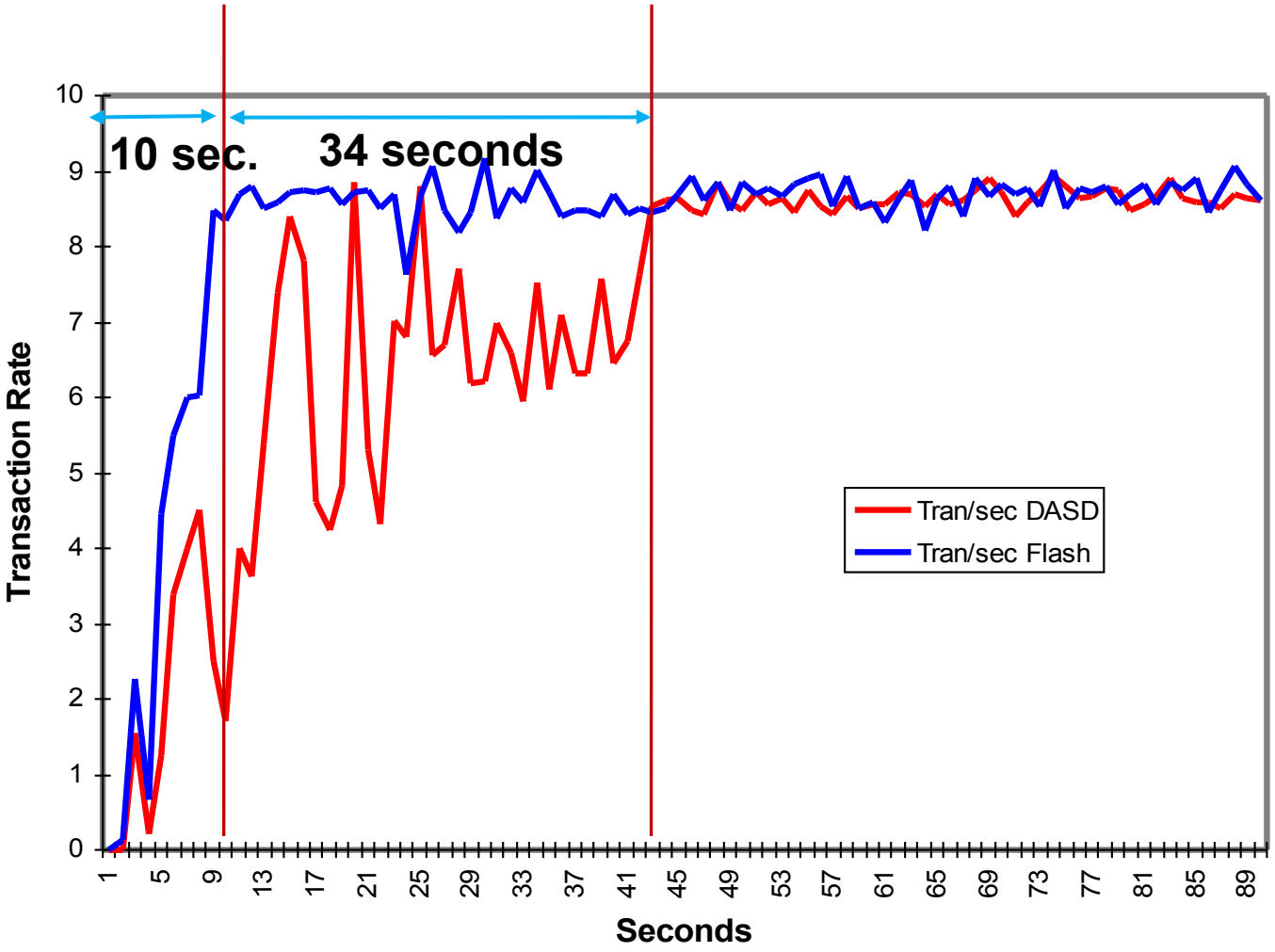
The "Night Work" is then stopped and OLTP work is started (WAS 1 and WAS 2)
Measure the time needed to bring the OLTP work to full speed.



~14GB is paged back in from Auxiliary storage

Morning Transition - Results

❖ **During morning transition, workloads using Flash Express reached peak throughput in under 1/4th the time**



Paging to **DASD** required about **44 seconds** for the workload to reach steady state

Paging to **Flash** required only **10 seconds** for the workload to reach steady state

Workload Transition

Morning Transition - Results Apparent in First 45 Seconds

Transaction completion & response time	DASD	Flash	Improvement
Total Transactions within first **45** seconds	251	343	**37% increase**
Average response time within first **45** seconds	0.62	0.06	**90% reduction**

Units in seconds

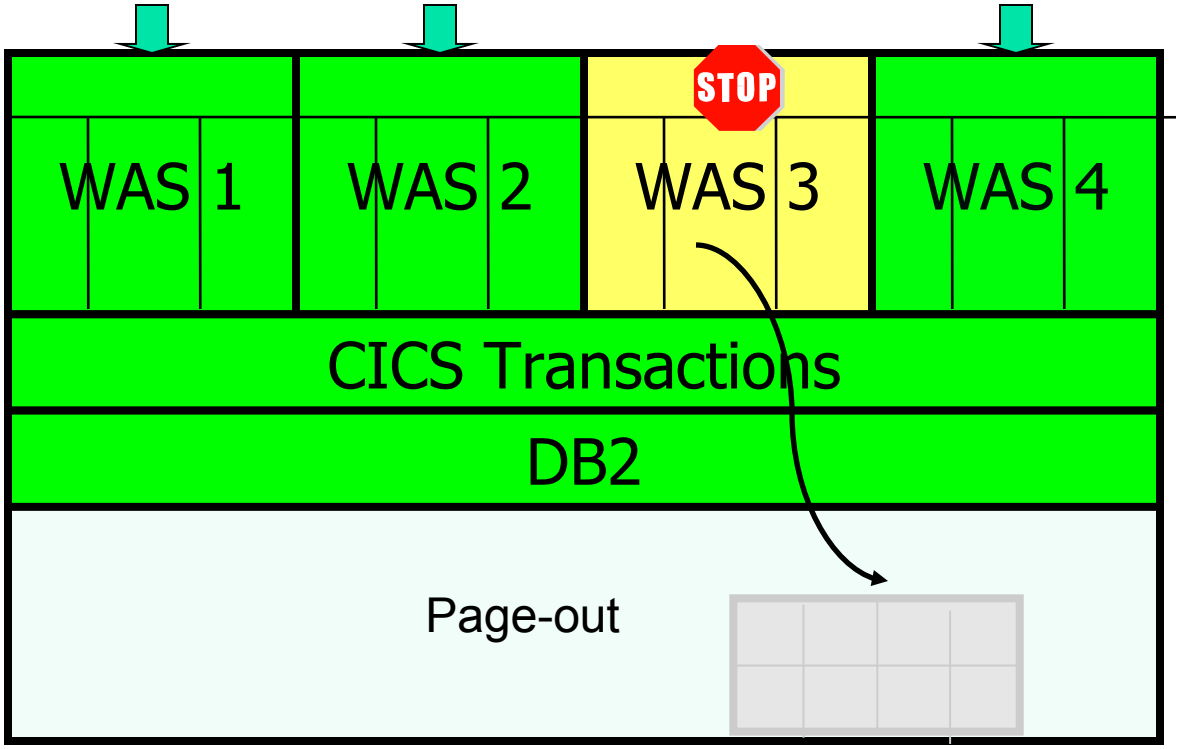
❖ **Paging to Flash Express during morning transition showed up to a 10 times faster response time and up to a 37% increase in throughput within the first 45 seconds**

(1) Test was for the first 45 seconds of morning transition time

II. SVC Dump

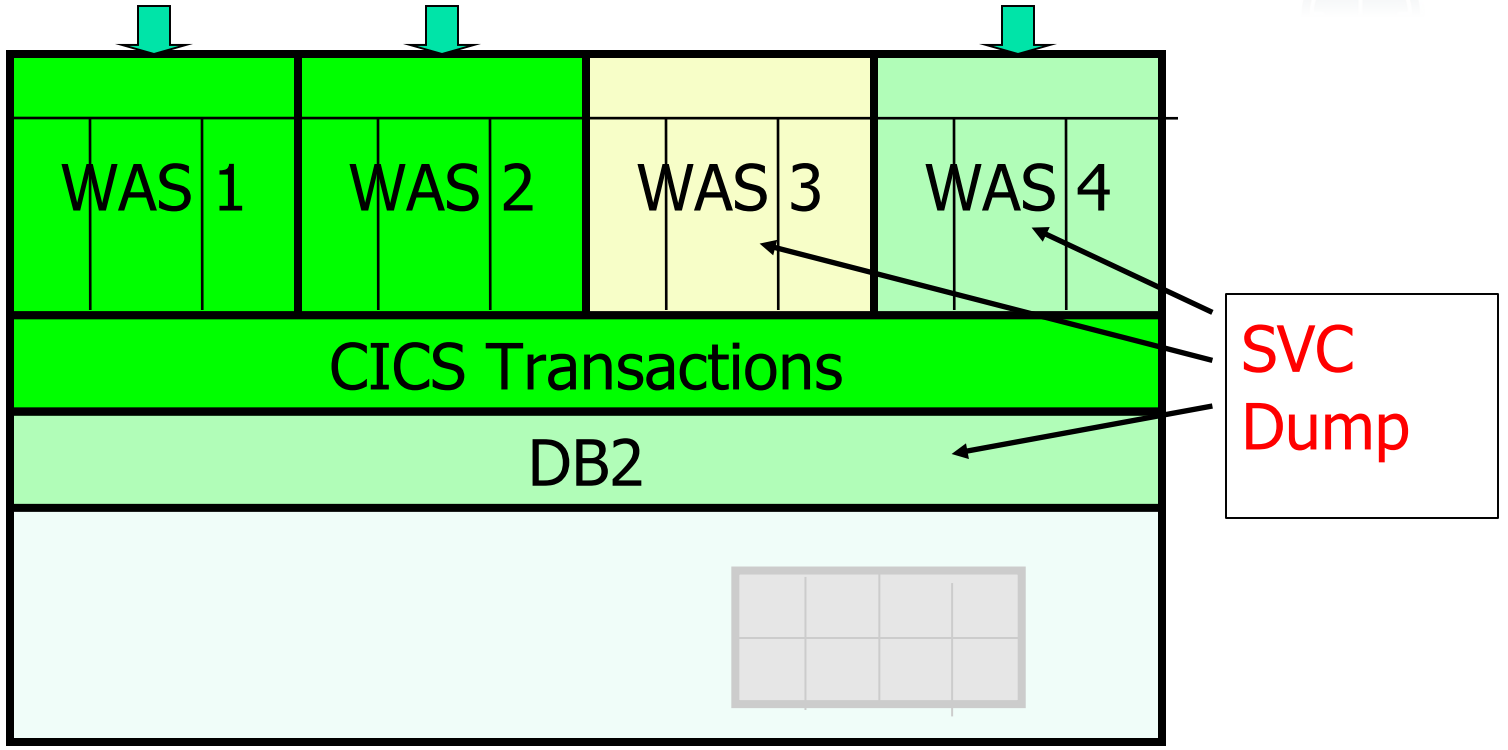
SVC dump with pages out

Three of four WAS instances were active.
One WAS instance was stopped and most pages were paged out.



SVC Dump- Diagnostics capture

Capture an SVC dump of WAS instance 3 and 4, and DB2.
Measure the capture time for the SVC dump.



SVC Dump - Results

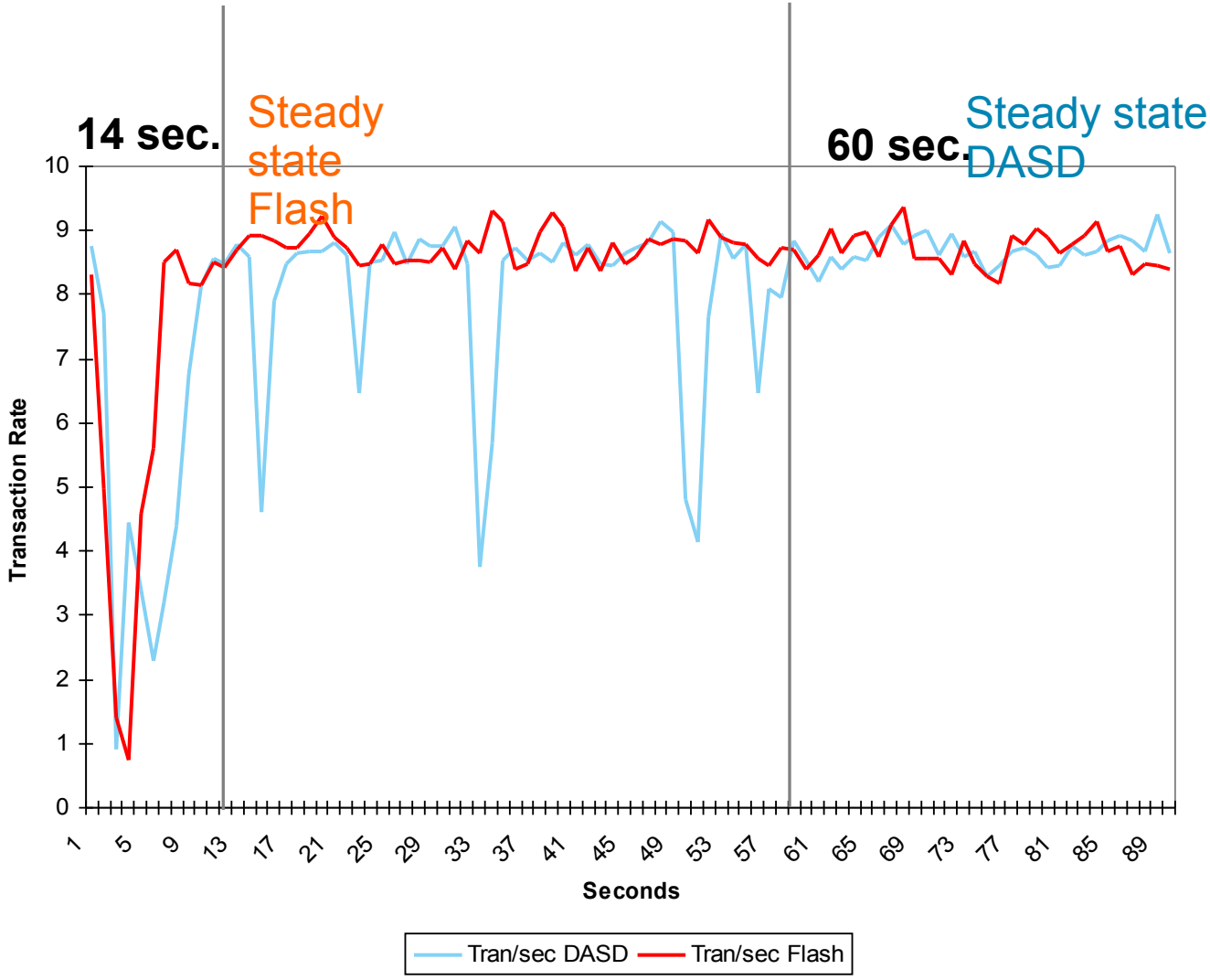
❖**Flash Express SVC dump elapsed time was up to 25% shorter**

SVC Dump Metrics	DASD	Flash
SVC Dump size (in bytes):	18GB	18GB
% of pages from Aux storage:	50%	53%
DUMP Elapsed time:	**189**	**143**
Max address space non-dispatchable seconds	**58.89**	**13.74**
System non-dispatchable seconds	**1.34**	**0.55**

Let's graph these results….

SVC Dump - Results

❖**In SVC dump test, steady state performance was achieved up to 4 times faster ***



Focus on first 90 seconds.

** Transaction steady state was reached in 14 seconds with Flash Express, vs. 60 seconds DASD*

z/OS Java SDK 7:16-Way Performance Shows up to 60% Improvement

64-bit Java Multi-threaded Benchmark on 16-Way

Aggregate 60% improvement from zEC12 and Java7SR3

- **zEC12 offers a ~45% improvement over z196 running the Java Multi-Threaded Benchmark**
- **Java7SR3 offers an additional ~13% improvement** (-Xaggressive + Flash Express pageable 1Meg large pages)

WAS benchmark: z/OS Performance for Pageable Large Pages

❖ **The WAS Day Trader benchmarks showed up to an 8% performance improvement using Flash Express.**

Java 7 SR3	JIT	Java Heap	Multi Threaded	WAS Day Trader 2.0
31 bit	yes	yes	4%	
64 bit	yes		1%	3%
64 bit		yes	4%	5%

* WAS Day Trader 64-bit Java 7 SR3 with JIT code cache & Java Heap

DETAILS

- **64-bit Java heap (**1M fixed large pages (FLPs) or 1M Pageable (PLPs)) versus 4k pages
  Java heap 1M PLPs improve performance by about
  - **4%** for Multi-Threaded workload
  - **5 %** for WAS Day Trader 2.0
- **64-bit** Java 7 SR3 with **JIT code cache** 1M PLPs vs without Flash
  - **3** % improvement for traditional WAS Day Trader 2.0*
  - **1** % improvement for Java Multi-Threaded workload
- **31-bit** Java 7 SR3 with **JIT code cache and Java heap** 1M PLPs vs without Flash
  - **4 %** improvement for Java Multi-Threaded workload

** Note: This test used 64-bit Java 7 SR3 with JIT code cache & Java Heap leveraging Flash and pageable large pages. Also , tests used WAS Day Trader app that supports PLP; earlier version of 31-bit Java did not allocate 1M large pages*

Performance Summary for Flash Express(1)

WORKLOAD TRANSITION

- **During morning transition, workloads using Flash Express reached peak throughput in under 1/4th the time**
- **Paging to Flash Express during morning transition showed up to a 10 times faster response time and up to a 37% increase in throughput within the first 45 seconds**

WAS JAVA PERFORMANCE BENCHMARKS

- **The WAS Day Trader benchmarks showed up to an 8% performance improvement using Flash Express.(2)**

** This test used 64-bit Java 7 SR3 with JIT code cache & Java Heap leveraging Flash and pageable large pages.*

Improved Availability During Diagnostics

- **In SVC dumps, availability was up to 4 times higher for workloads and up to twice as high for systems***
- **In SVC dump tests, steady state performance was achieved up to 4 times faster ***
- **Flash Express SVC dump elapsed time was up to 25% shorter**

** Transaction steady state was reached in 14 seconds with Flash Express, vs. 60 seconds DASD.*

DB2

- **Up to 28% improvement in DB2™ throughput due to faster CPU and leveraging Flash Express with Pageable Large Pages (PLP)***
- **Workloads leveraging Flash Express with PLP can see up to a 8%** price performance improvement over the z196.**

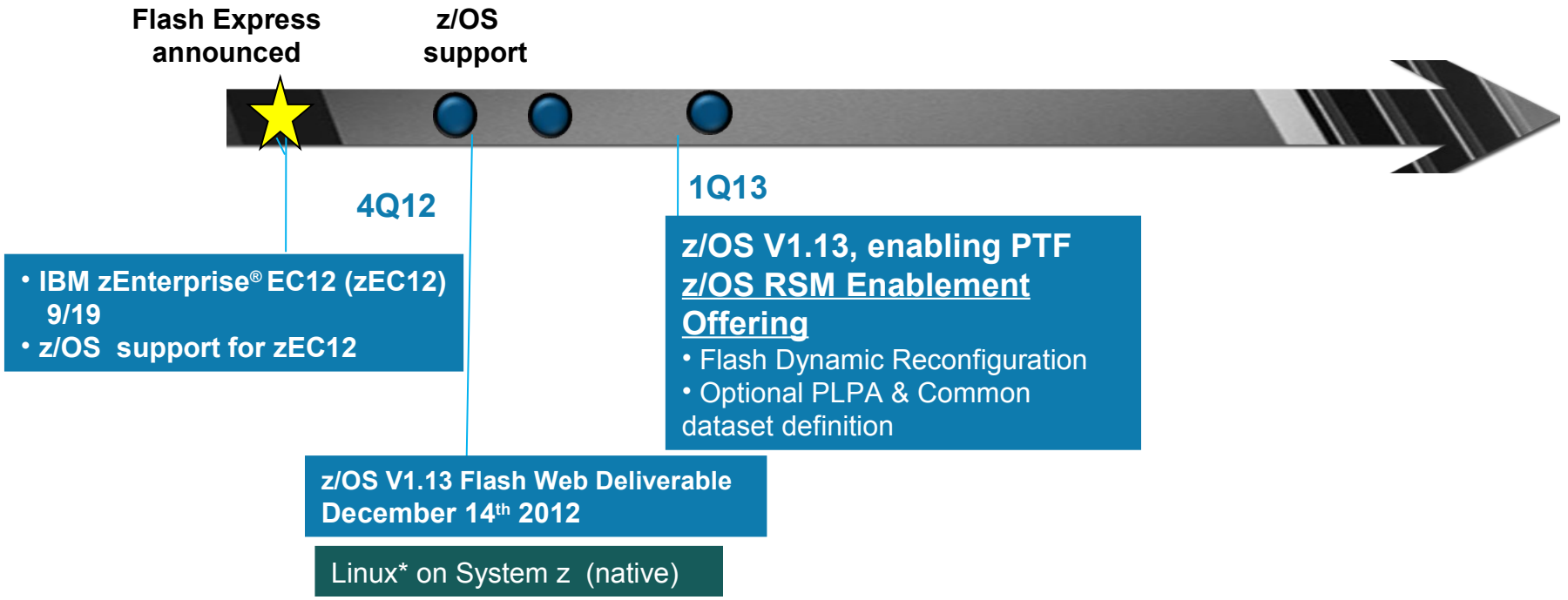
** PLP for DB2 helps DB2 to achieve **"additional" up to 3% additional performance on top of zEC12 CPU expected throughput improvements of 25%.***
*** based on average 5% discount for zEC12 workloads under the AWLC pricing plus up to 3% more performance per MSU with Flash Express.*

(1) All tests are comparing the use of Flash Express as compared to using DASD (DS8800)
(2) System non dispatchability and address space non dispatchability time were dramatically reduced enabling work to be processed that would otherwise have been stopped

z/OS Flash Roadmap

Flash Express Exploitation

Flash support in z/OS sets the stage for further use



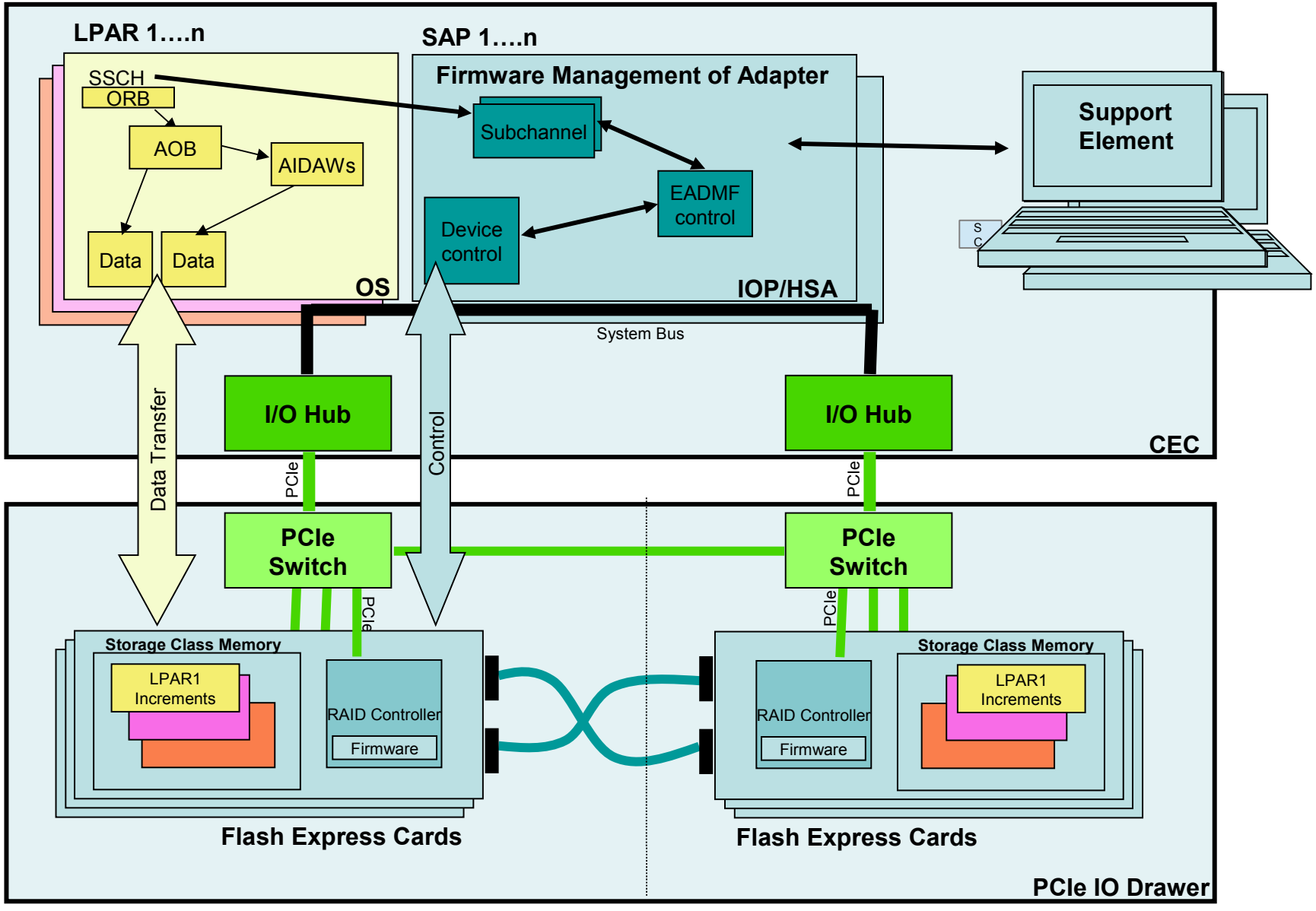
- ***Planned*** **Flash Express and pageable large page exploiters:**
  - DB2 for z/OS
  - Java SDK7
  - WAS Liberty Profile v8.5
  - IMS™ 12
  - z/OS V1.13 Language Environment®
  - Other (CICS®)

Expect continued middleware exploitation for 1MB pageable large pages

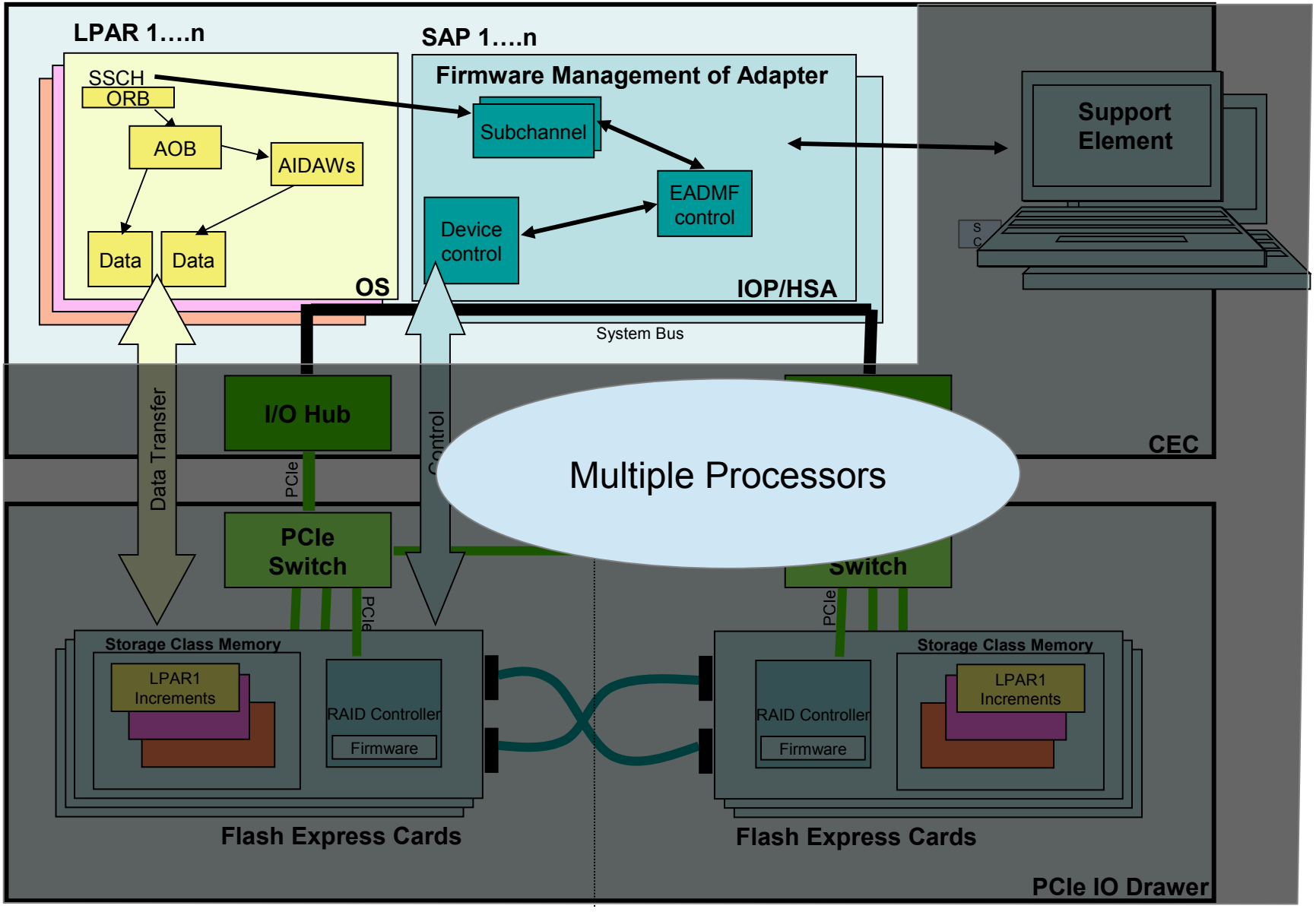
Flash Express Implementation

- ✓ System Overview
- ✓ Redundant Physical Structures
- ✓ Data Protection Mechanisms
- ✓ Data and Key Encryption
- ✓ Non-Disruptive Service Techniques

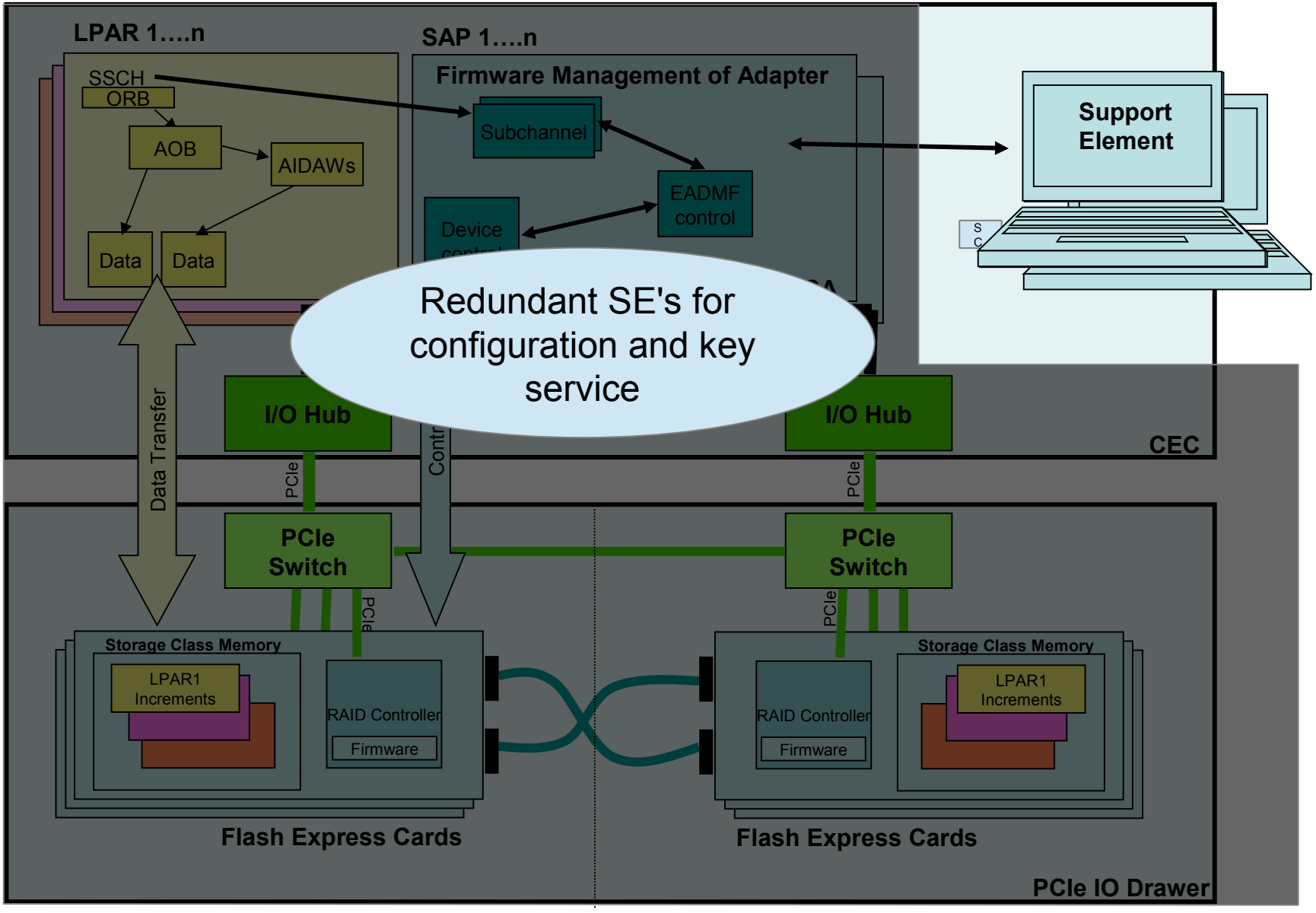
FLASH Express System Overview



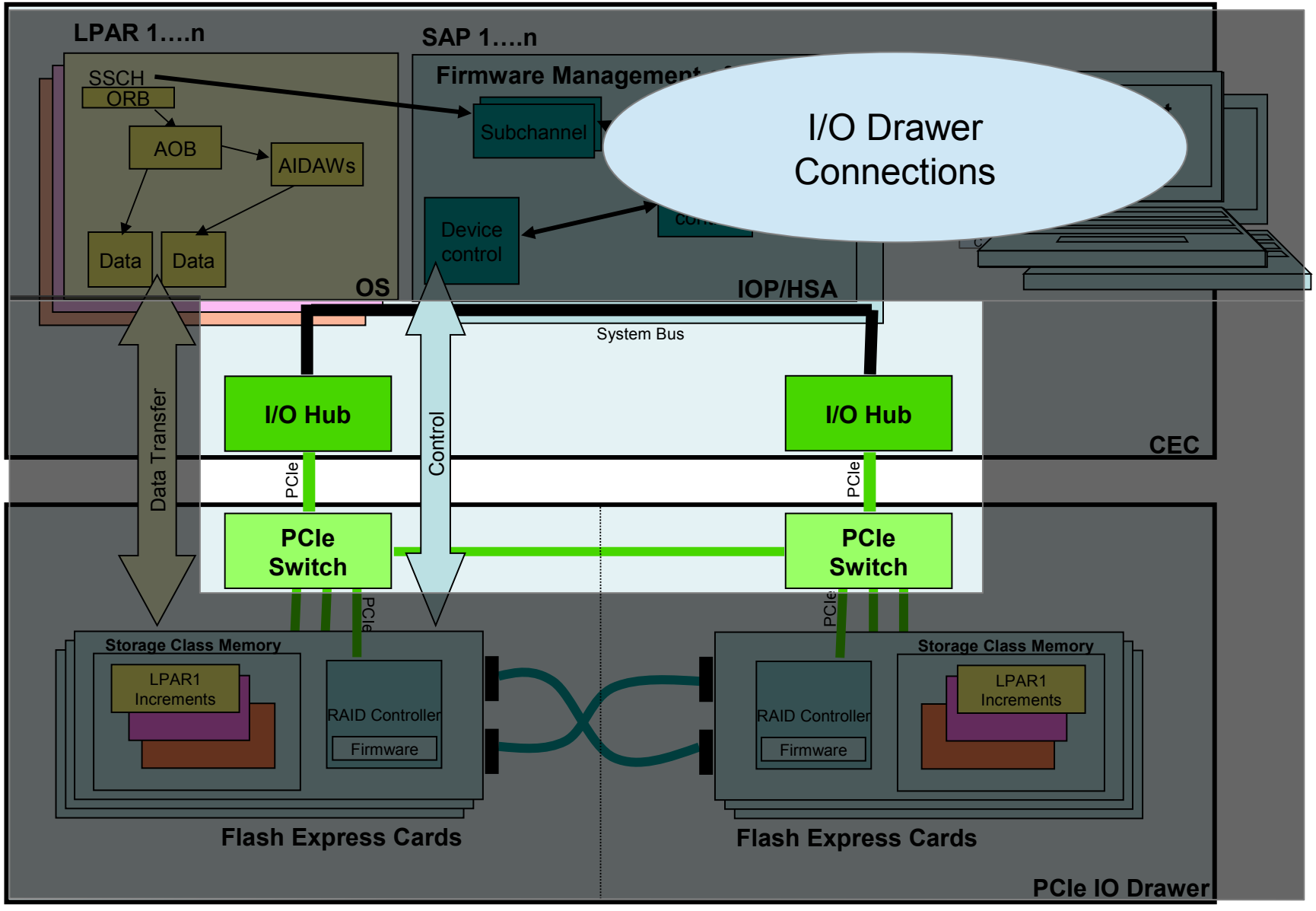
Redundant Physical Structures



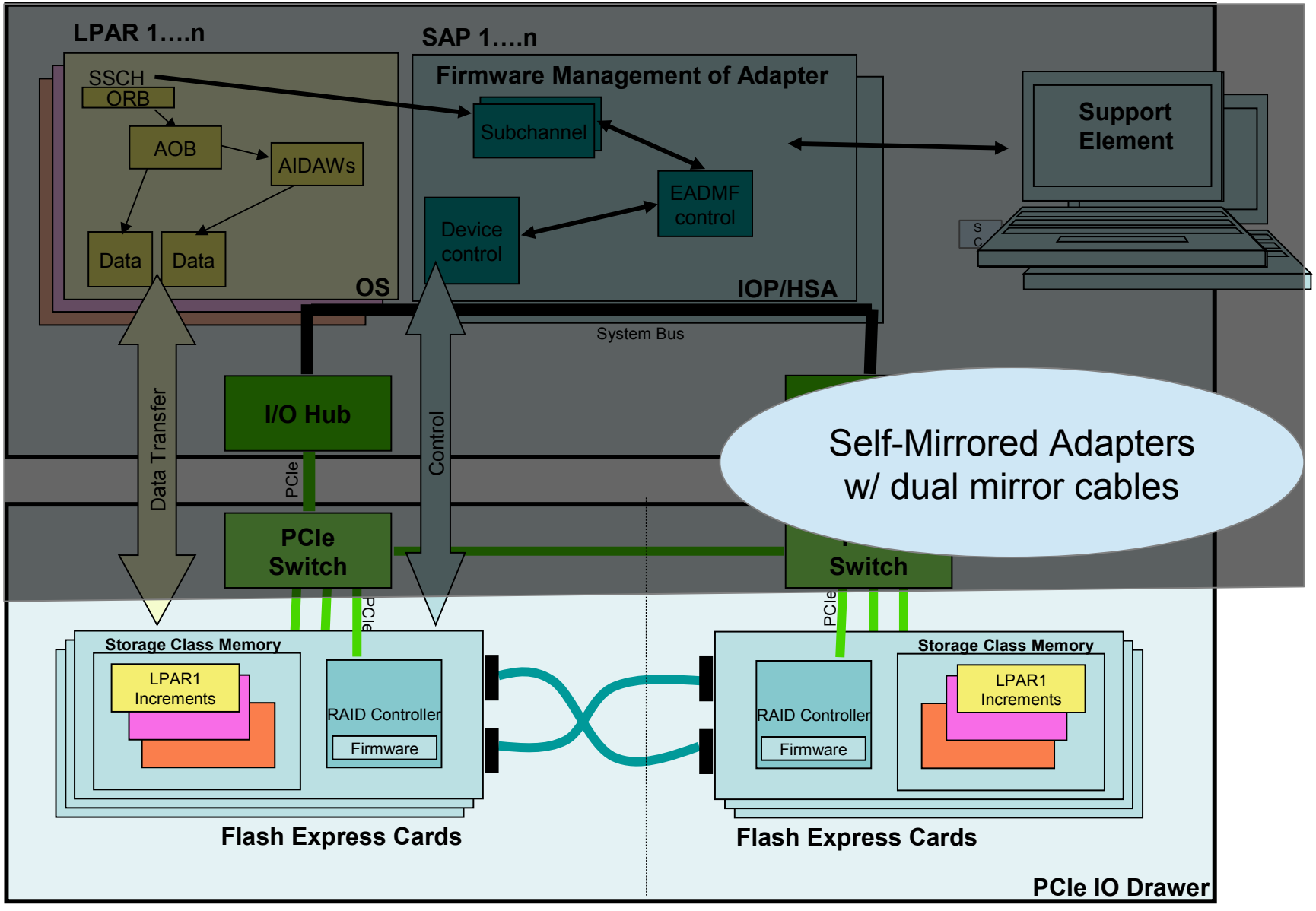
Redundant Physical Structures



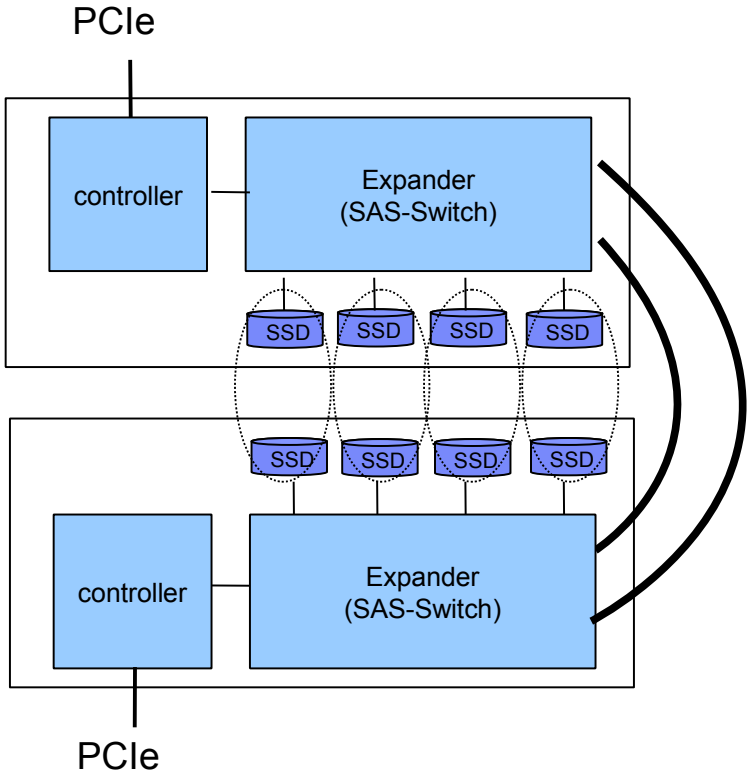
Redundant Physical Structures



Redundant Physical Structures



Data Protection Mechanisms

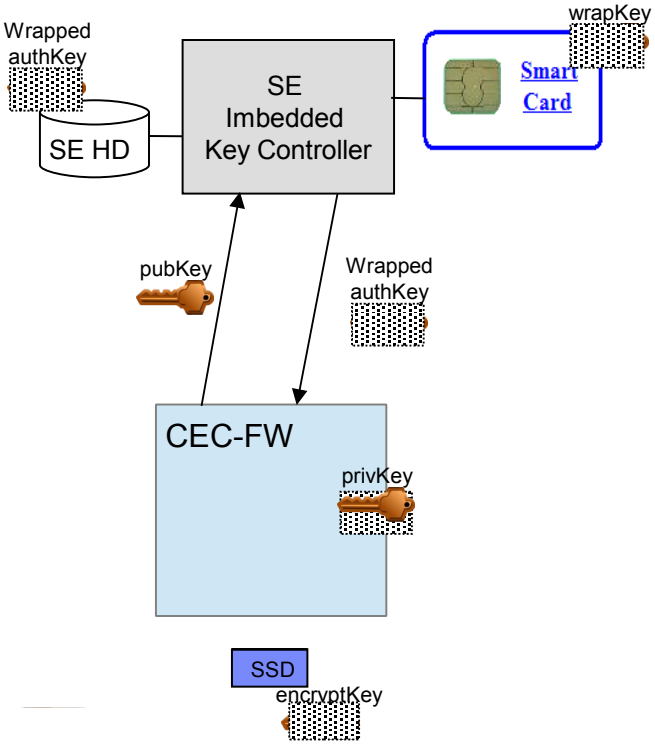


- ✓ RAID10: Protection and performance
  - RAID0 = Striping
  - RAID1 = Mirroring
  - RAID10 = Striped mirrorred data
- ✓ CRC and block seq. number stored on SSD
- ✓ Additional CRC around block transfer

- ✓ Comm links (SAS, PCIe) provide embedded protection & recovery
- ✓ CEC-based hardware address protection on communication from adapter
- ✓ ECC on internal system memory

Data and Key Encryption

- ✓ On SSD, data is protected with inline encryption (hidden encryptKey)
- ✓ Access to SSD is via authentication key (authKey) served from SE



During Flash install, in smart card on SE:

- Create authKey (aka PIN)
- Wrap authKey in an encrypted file
- wrapKey stored in smart card
- Wrapped key file stored on SE

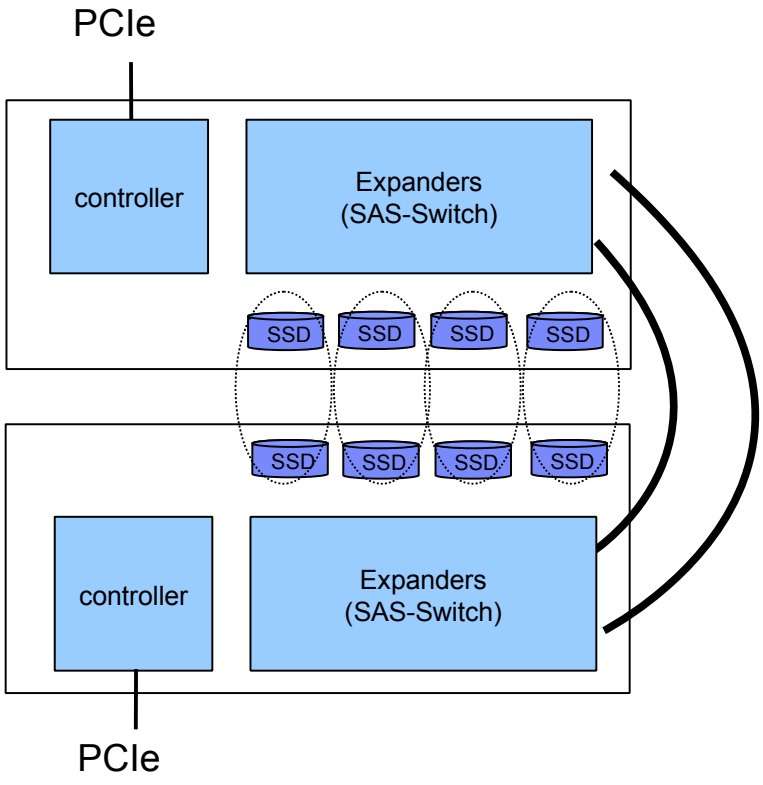
SE ⟶ CEC-FW authkey service:

- asymetric protocol – pub/private
- IOP sends public key to SE
- In smart card, Key file unwrapped then encrypted with CEC pubKey
- Encrypted authKey sent to CEC
- CEC 'unwraps' authKey using its privKey

- ✓ AuthKey used during SSD format and subsequent power cycles

Non-disruptive Service Strategy

- ✓Firmware updates
  - » Adapter
  - » SSD
  - » Expanders
  - » CEC-FW
- ✓Adapter replacement
- ✓Cable replacement
- ✓Recoveries
  - » CEC
  - » Adapter
  - » SSD



THANK YOU