Using Linux block integrity in building and testing storage systems

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What we are doing?

Storage appliance

- 550PB installed, up to 18PB per system
- OpenPOWER storage controllers

Data integrity is vital

Problem statement

Data integrity for distributed RAID

- detect stealth data corruption
- no external metadata storage

Naive approach

- HDD extended sector
  - 520/528
  - 4104/4112/4160/4224
- FORMAT UNIT (took 16 hours for 12TB)
- and…

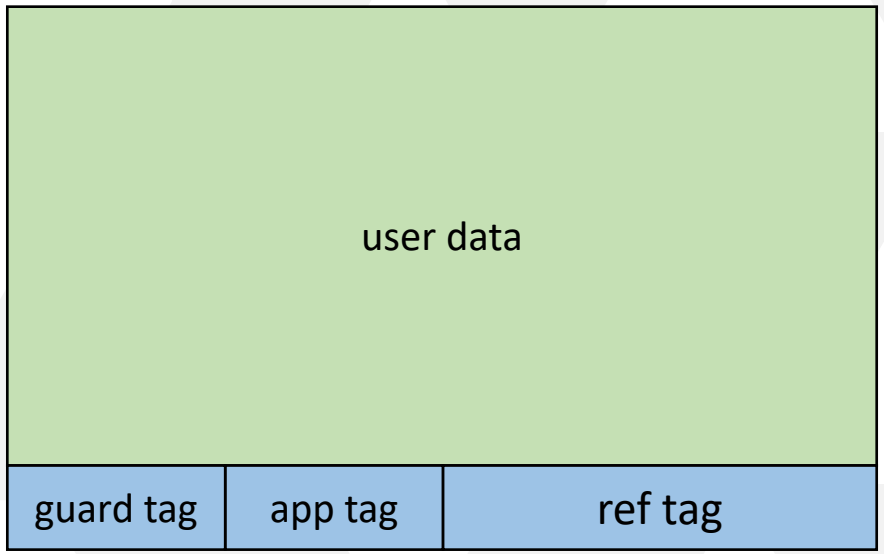
Naive approach

- HDD extended sector
  - 520/528
  - 4104/4112/4160/4224
- FORMAT UNIT (took 16 hours for 12TB)
- and… nothing works:
  - unsupported sector size 4160
  - in sd.c sector must be equal to $512*2^n$

RTFM!

- 15 years ago
- T10 PI (Protection Information)
  - 8b per sector
  - format defined by T10
- See also:
  - DIF, DIX, EEDP

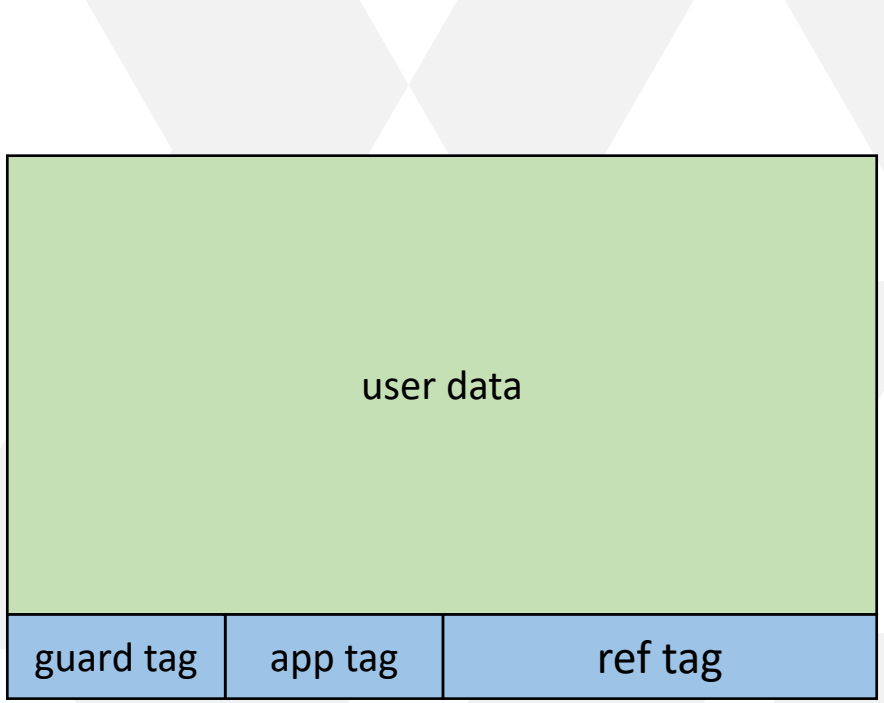
T10 PI (theory)

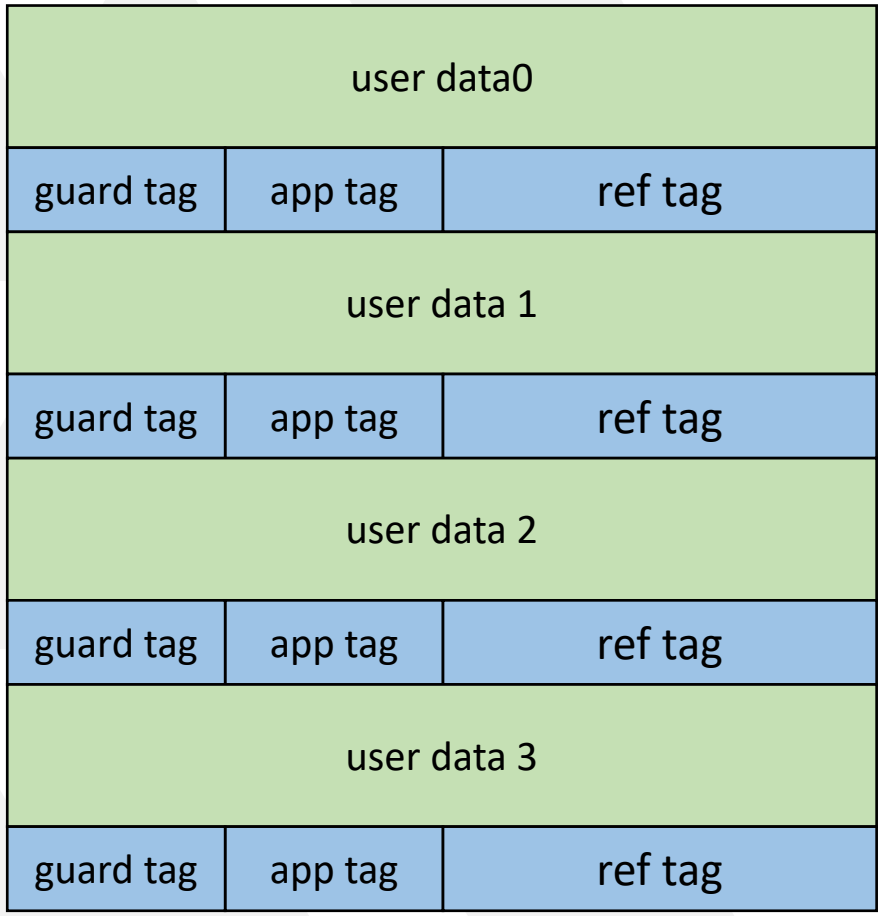


For each logical block

- guard tag – checksum
- app tag – application meta
- ref tag – application meta (sometimes)

T10 PI (theory)





Kernel blk_integrity API

- https://www.kernel.org/doc/html/latest/block/data-integrity.html
- register device as integrity capable:

  int blk_integrity_register(gendisk, blk_integrity_profile);
- attach metadata:

  struct bip * bio_integrity_alloc(bio, gfp_mask, nr_pages);

  int bio_integrity_add_page(bio, page, len, offset);
- supports custom metadata model

T10 PI (practice)

- SCSI FORMAT UNIT
  - sg_format --format --size 4096 --fmtpinfo=2 -vvv /dev/sda
    - Type 1 “--fmtpinfo=2”
    - Type 3 “--fmtinfo=3 --pfu=1”
    - 6 or 10 bytes?
- No Type 3 support for NL SAS drives
- 16 hours later…

T10 PI (practice)

Nothing happens :(however:

- lower capacity (-0.7%)
- SCSI stack considers device as Type 1 DIF
- still no integrity on block level:

  /sys/block/sda/integrity/device_is_integrity_capable -> 0

  /sys/block/sda/integrity/tag_size -> 0

sg_readcap -v --long /dev/sdc

read capacity(16) cdb: 9e 10 00 00 00 00 00 00 00 00 00 00 00 20 00 00

Read Capacity results:

Protection: prot_en=1, p_type=0, p_i_exponent=0 [type 1 protection]

Logical block provisioning: lbpme=0, lbprz=0

Last logical block address=2424569855 (0x9083ffff), Number of logical blocks=2424569856

Logical block length=4096 bytes

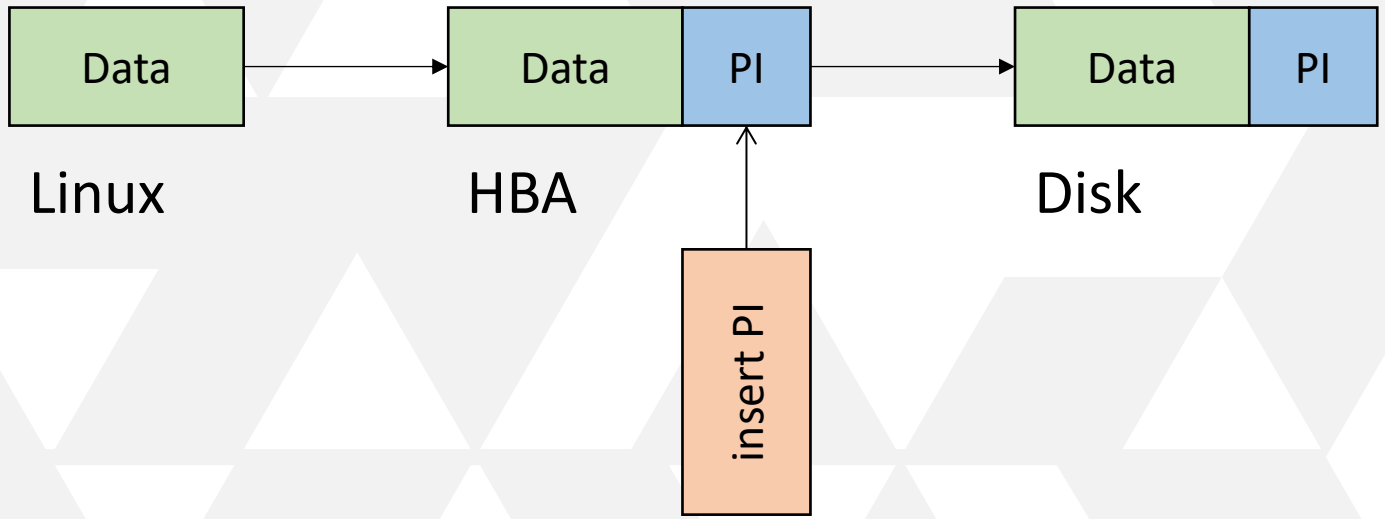
Logical blocks per physical block exponent=0

Lowest aligned logical block address=0

Hence:

Device size: 9931038130176 bytes, 9470976.0 MiB, 9931.04 GB

T10 PI (HBA)



T10 PI (HBA)

- SAS HBA may require explicit DIF enablement:

  example for LSI: options mpt3sas prot_mask=63

- block layer detects integrity format T10-DIF-TYPE1-CRC
- looks good, but tag_size is still zero:

  /sys/block/sda/integrity/tag_size -> 0

T10 PI (ATO)

- tag_size – application metadata size
- Control Mode Page (0x0A), ATO bit
  - sg_wr_mode -v -p 0a -c

    00,00,00,00,00,80,00,00,00,00,00,00 -m

    00,00,00,00,00,80,00,00,00,00,00,00 /dev/sda
  - use –s for persistence

T10 PI (driver)

- Everything in place but still nothing works:

  mpt3sas_cm0: log_info(0x31120309): originator(PL), code(0x12), sub_code(0x0309)

  mpt3sas_cm0: log_info(0x31120434): originator(PL), code(0x12), sub_code(0x0434)

- Driver version may be important (or vendor)

T10 PI (all together)

- It works!
  - Just need a correct format, drive settings, HBA settings and HBA driver
    - /sys/block/sda/integrity/device_is_integrity_capable -> 1
    - /sys/block/sda/integrity/tag_size -> 2
    - /sys/block/sda/integrity/format -> T10-DIF-TYPE1-CRC
- We can read and write data

NVMe PI

A copy of T10 PI

- optional
- configured as namespace format
- different namespaces with different formats
- firmware issues
- noop profile

```
nvme id-ns -H /dev/nvme1n1
...
dpc     : 0x1f
  [4:4] : 0x1       Protection Information Transferred as Last 8 Bytes of Metadata Supported
  [3:3] : 0x1       Protection Information Transferred as First 8 Bytes of Metadata Supported
  [2:2] : 0x1       Protection Information Type 3 Supported
  [1:1] : 0x1       Protection Information Type 2 Supported
  [0:0] : 0x1       Protection Information Type 1 Supported
...
dps     : 0x3
  [3:3] : 0         Protection Information is Transferred as Last 8 Bytes of Metadata
  [2:0] : 0x3       Protection Information Type 3 Enabled
...
LBA Format  0 : Metadata Size: 0   bytes - Data Size: 512 bytes - Relative Performance: 0x1 Better
LBA Format  1 : Metadata Size: 8   bytes - Data Size: 512 bytes - Relative Performance: 0x3 Degraded
LBA Format  2 : Metadata Size: 0   bytes - Data Size: 4096 bytes - Relative Performance: 0 Best
LBA Format  3 : Metadata Size: 8   bytes - Data Size: 4096 bytes - Relative Performance: 0x2 Good (in use)
```

How to code with PI?

- Without specific hardware
  - even on laptop
- Run tests in CI

scsi target

data file

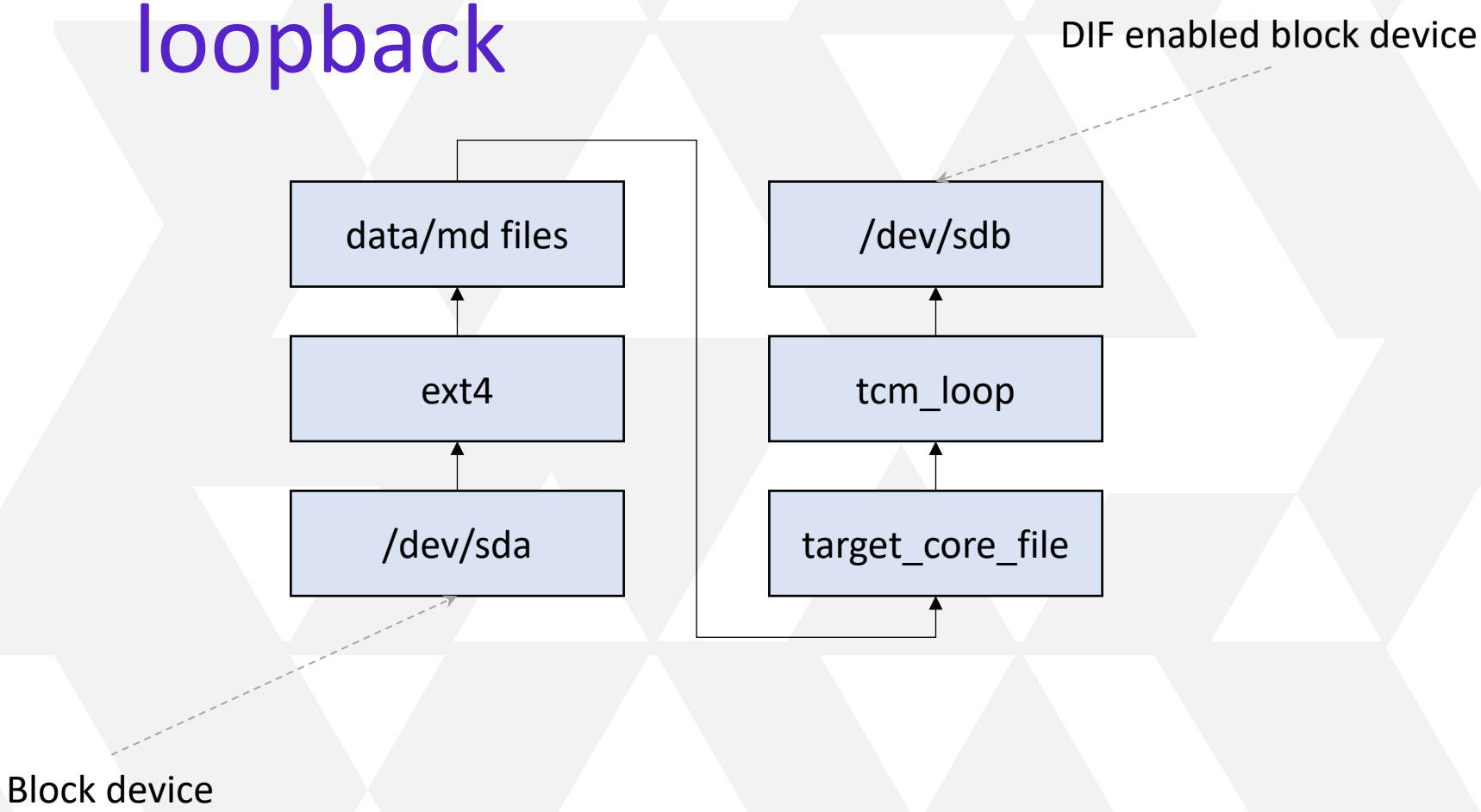
+ metadata file

+ fileio backend

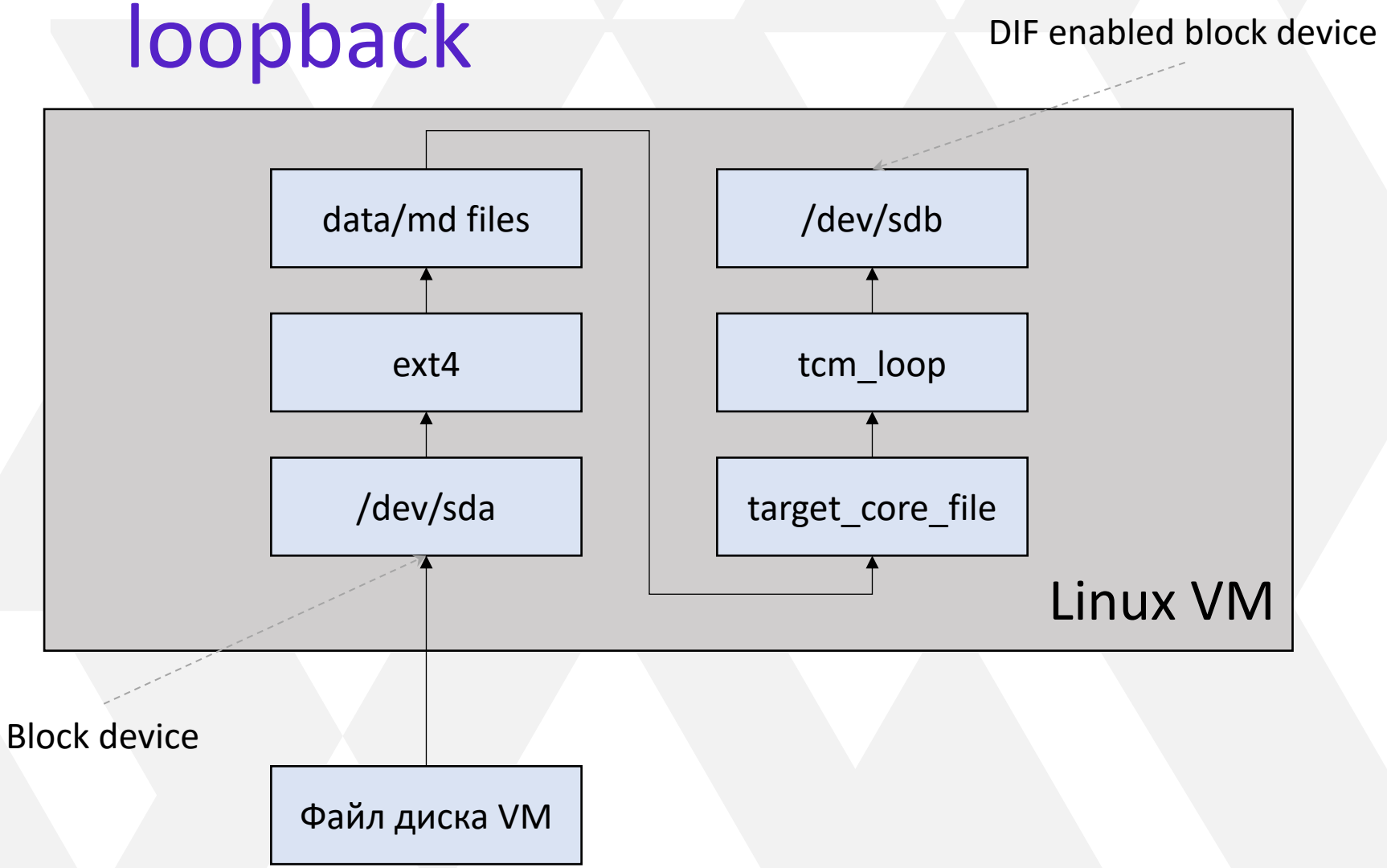
+ loopback frontend

= scsi device with DIF on any hardware

loopback


DIF enabled block device
data/md files
ext4
/dev/sda
/dev/sdb
tcm_loop
target_core_file
Block device

loopback


DIF enabled block device
data/md files
ext4
/dev/sda
/dev/sdb
tcm_loop
target_core_file
Linux VM
Block device
Файл диска VM

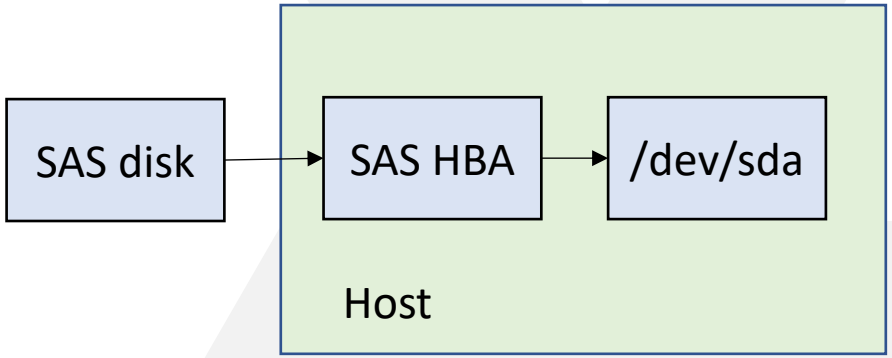
Tests in CI

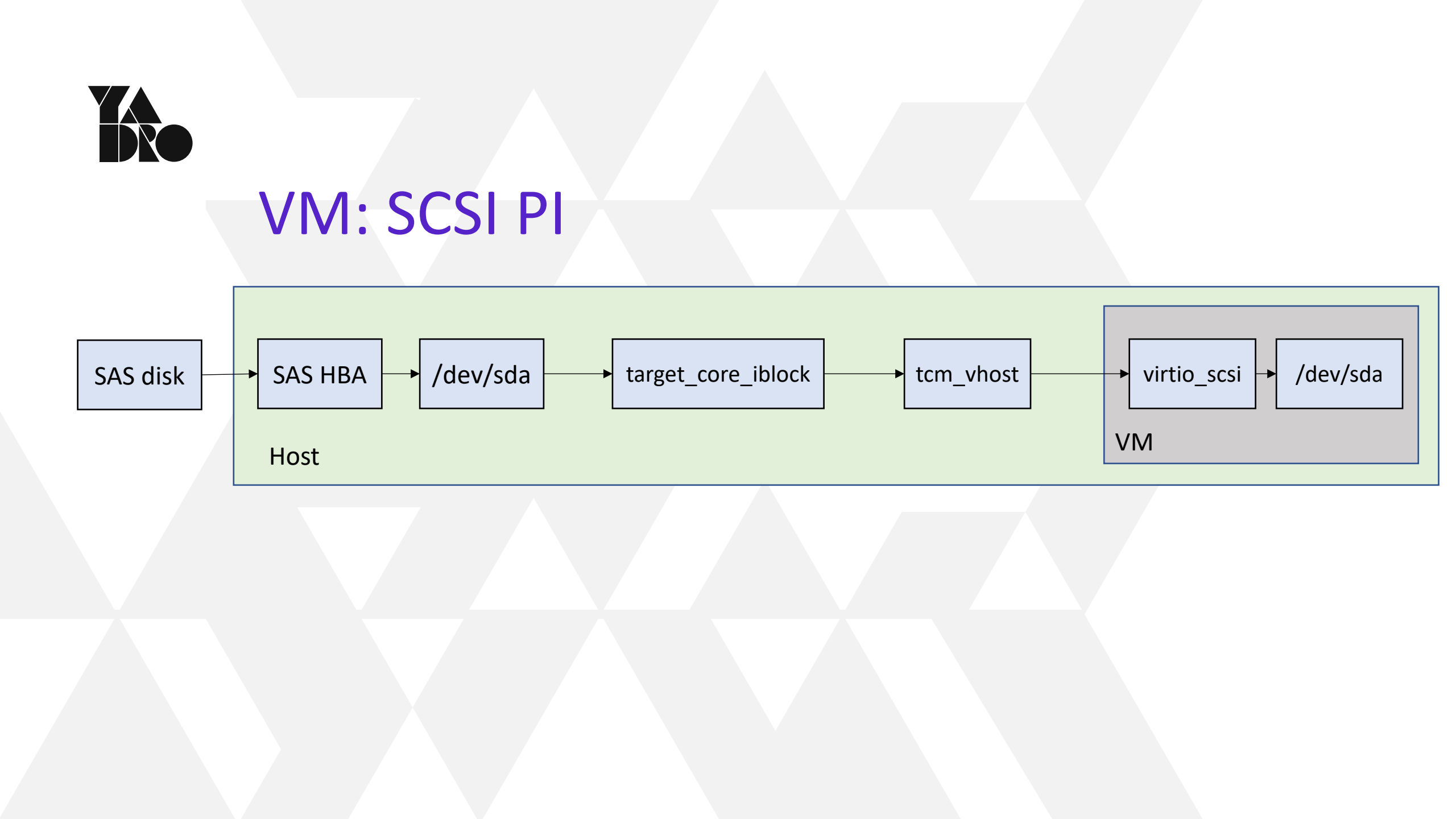
- T10 PI devices for VMs
- component tests
  - NVMe/SCSI devices with PI support
- integration tests
  - VMs with shared drives
  - external configuration

VM: NVMe PI

- PCI passthrough
- one VM per disk
  - dual port drives may help
  - or SR-IOV (in future?)

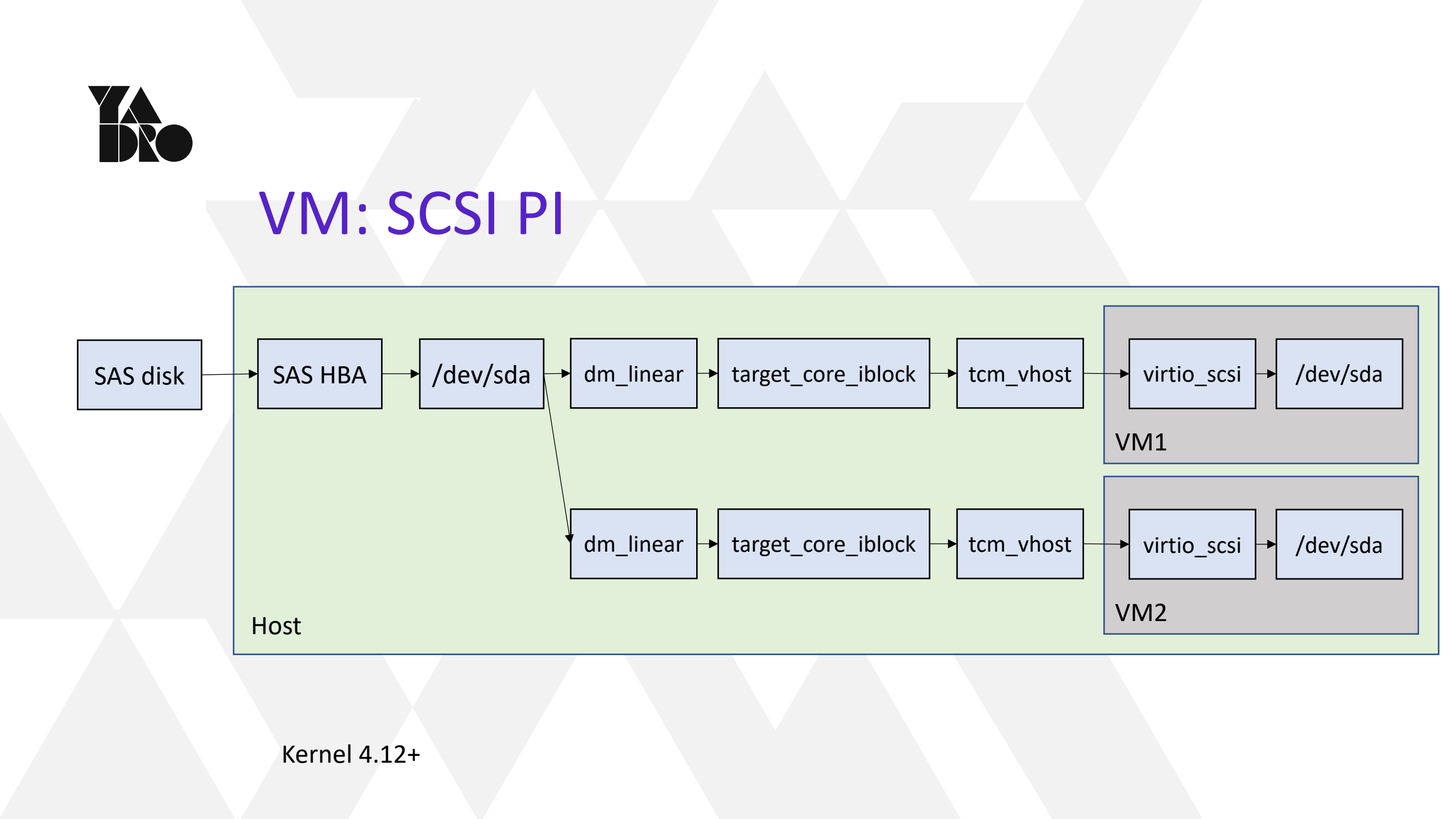
VM: SCSI PI





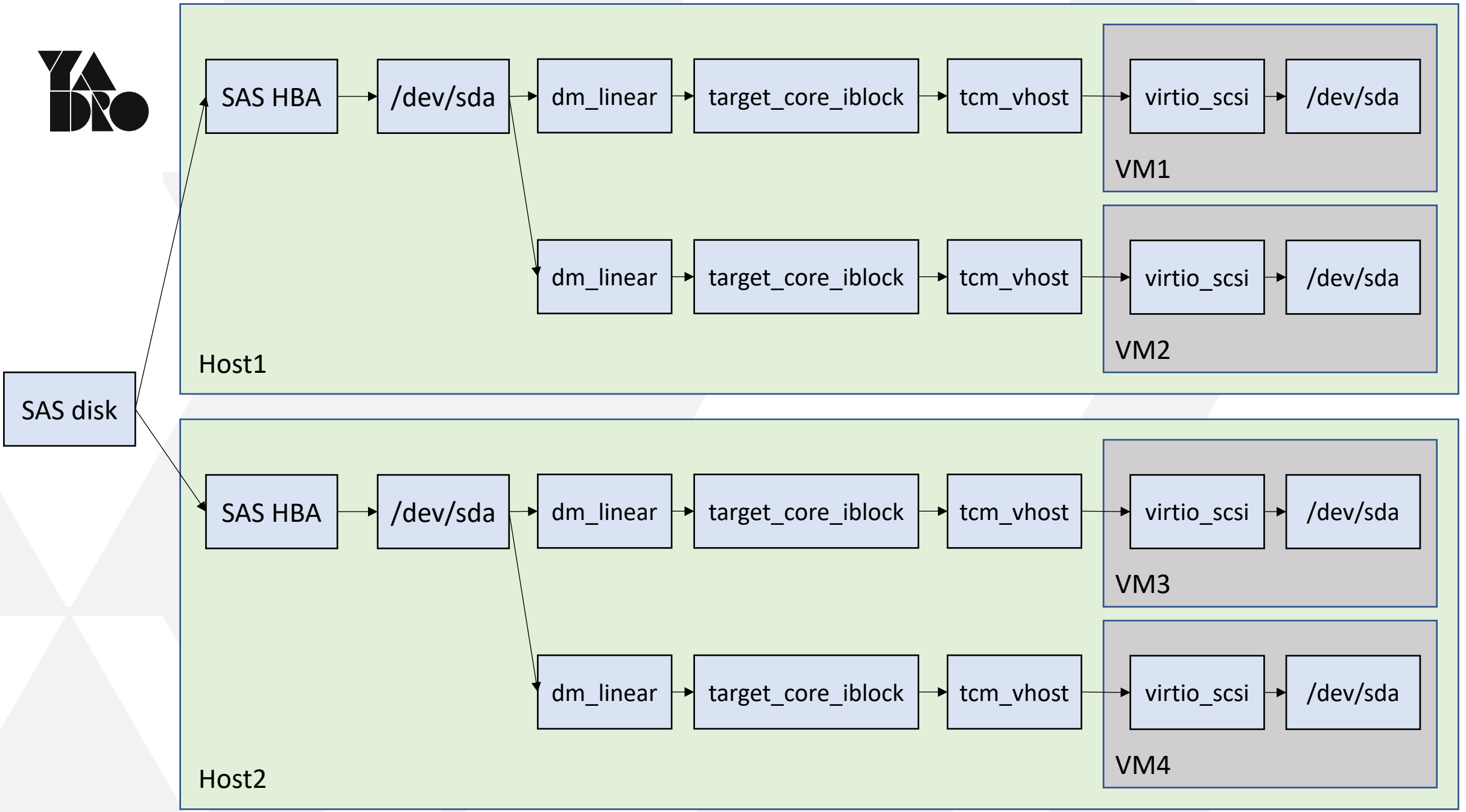
VM: SCSI PI

SAS disk
SAS HBA
/dev/sda
target_core_iblock
tcm_vhost
virtio_scsi
/dev/sda
Host
VM



VM: SCSI PI

Kernel 4.12+


SAS disk
Host1
SAS HBA
/dev/sda
dm_linear
target_core_iblock
tcm_vhost
virtio_scsi
/dev/sda
VM1
dm_linear
target_core_iblock
tcm_vhost
virtio_scsi
/dev/sda
VM2
Host2
SAS HBA
/dev/sda
dm_linear
target_core_iblock
tcm_vhost
virtio_scsi
/dev/sda
VM3
dm_linear
target_core_iblock
tcm_vhost
virtio_scsi
/dev/sda
VM4

vhost_scsi

- no DIF/DIX again:(
- virtio_scsi/vhost_scsi seem to support T10 PI
  - VIRTIO_SCSI_F_T10_PI feature bit

vhost_scsi

- no DIF/DIX again:(
- virtio_scsi/vhost_scsi seem to support T10 PI
  - VIRTIO_SCSI_F_T10_PI feature bit
  - qemu 3.1+

```
<domain>
…
<devices>
…
<hostdev mode='subsystem' type='scsi_host' managed='no'>
    <source protocol='vhost' wwpn='naa.50014052ccc30dc0'/>
    <alias name='hostdev2'/>
    <address type='pci' domain='0x0000' bus='0x00' slot='0x07' function='0x0'/>
  </hostdev>
</devices>
 <qemu:commandline>
  <qemu:arg value='-set'/>
  <qemu:arg value='device.hostdev2.t10_pi=on'/>
 </qemu:commandline>
</domain>
```

vhost_scsi

VIRTIO_SCSI_F_T10_PI negotiated and nothing works:

- Bad block number requested
- 4096b bio => 4040b
- 8192b bio => 8080b
- 56b stolen from each sector

commit cdcdcaae8450a975e7d07e1bfec21f9b8c016d0c

Author: Greg Edwards <gedwards@ddn.com>

Date: Thu Jul 26 15:52:54 2018 -0400

scsi: virtio_scsi: fix pi_bytes{out,in} on 4 KiB block size devices

When the underlying device is a 4 KiB logical block size device with a protection interval exponent of 0, i.e. 4096 bytes data + 8 bytes PI, the driver miscalculates the pi_bytes{out,in} by a factor of 8x (64 bytes).

This leads to errors on all reads and writes on 4 KiB logical block size devices when CONFIG_BLK_DEV_INTEGRITY is enabled and the VIRTIO_SCSI_F_T10_PI feature bit has been negotiated.

What else?

SPDK:

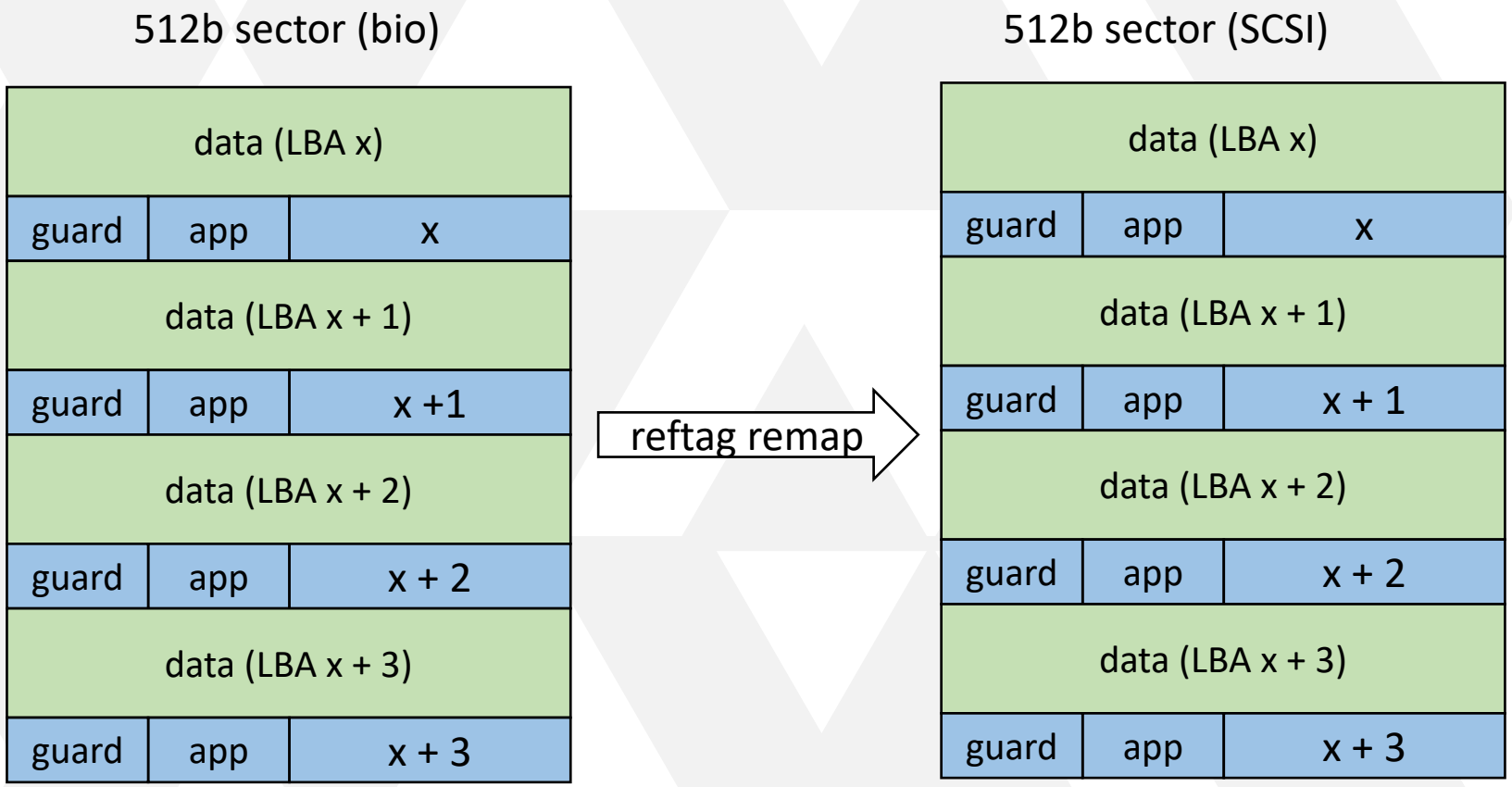
- NVMe bdev supports metadata
- vhost does not
- ppc64le memory issues

blk_integrity API (practice)

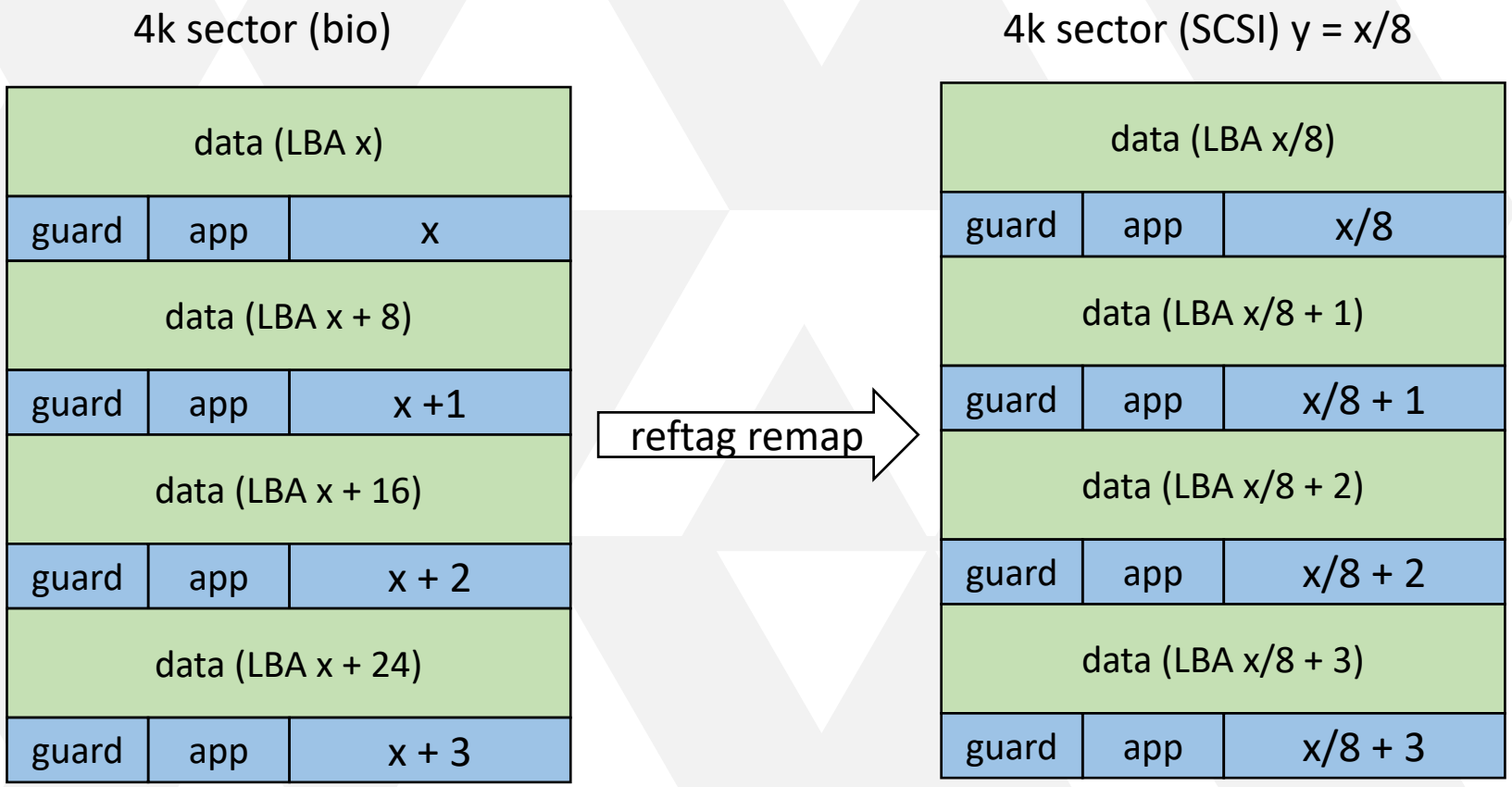
Common error: - EILSEQ, Logical block reference tag check failed

- in case of incorrect reference tag
  - LBA lower bits for PI Type 1
  - Linux 4k block issues

blk_integrity API (practice)



blk_integrity API (practice)



blk_integrity API (practice)

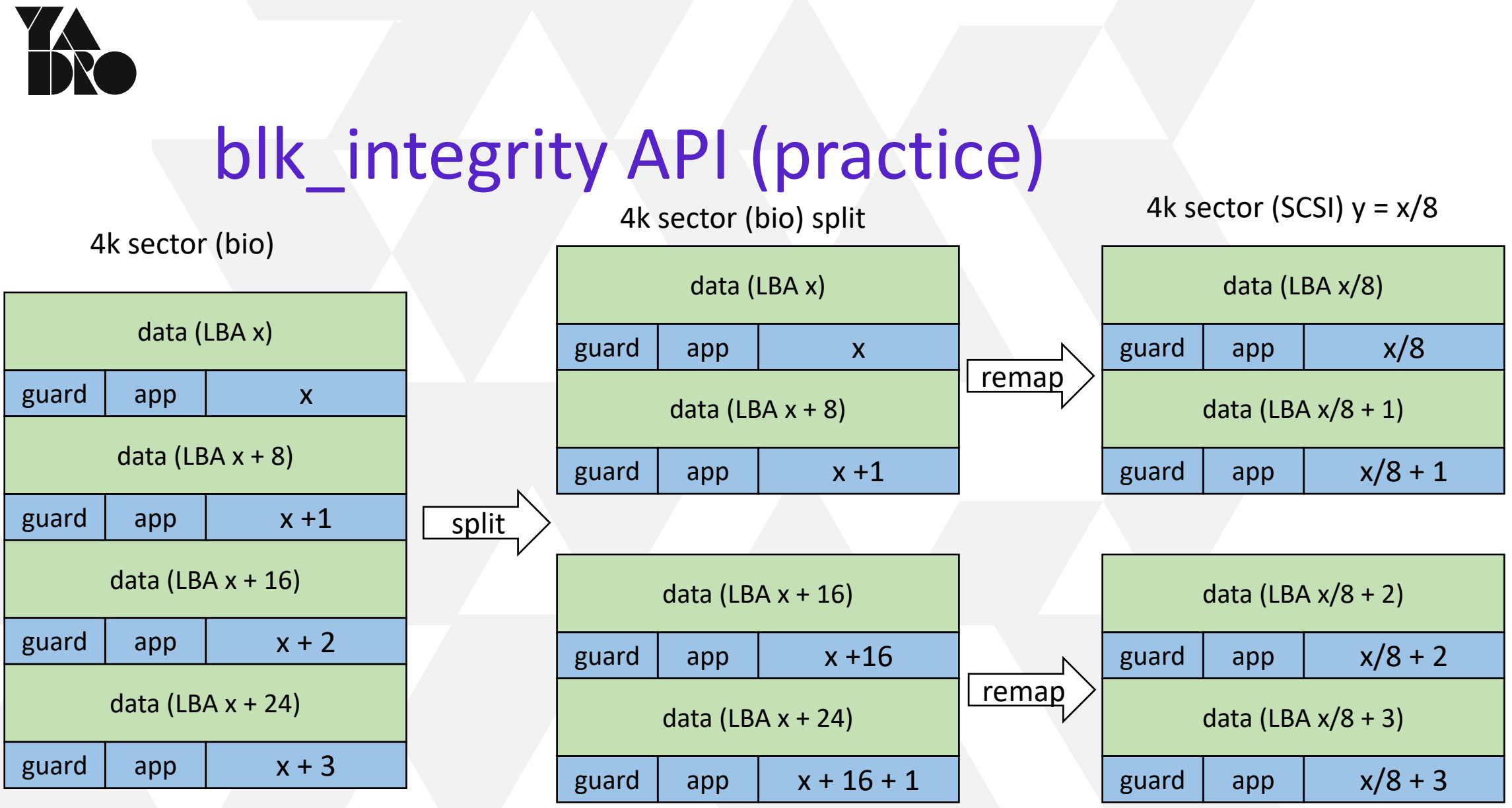
Common error: - EILSEQ

- request greater than 126 64к pages in virtio_scsi

blk_integrity API (practice)

Common error: - EILSEQ

- request greater than 126 64к pages in virtio_scsi
- or more than 32 pages in nvme
  - request split in scheduler
  - /sys/block/sda/queue/max_segments


blk_integrity API (practice)
4k sector (bio)
data (LBA x)
guard
app
x
data (LBA x + 8)
guard
app
x +1
data (LBA x + 16)
guard
app
x + 2
data (LBA x + 24)
guard
app
x + 3
split
4k sector (bio) split
data (LBA x)
guard
app
x
data (LBA x + 8)
guard
app
x +1
data (LBA x + 16)
guard
app
x +16
data (LBA x + 24)
guard
app
x + 16 + 1
remap
remap
4k sector (SCSI) y = x/8
data (LBA x/8)
guard
app
x/8
data (LBA x/8 + 1)
guard
app
x/8 + 1
data (LBA x/8 + 2)
guard
app
x/8 + 2
data (LBA x/8 + 3)
guard
app
x/8 + 3

blk_integrity API (practice)

Common error: - EILSEQ

- request greater than 126 64к pages in virtio_scsi
- or more than 32 pages in nvme
  - request split in scheduler
- or multiple metadata pages (nvme)
  - single MD page for PRP
  - /sys/block/sda/queue/max_integrity_segments

blk_integrity API (practice)

Common error: - EILSEQ

- request greater than 126 64к pages in virtio_scsi
- or more than 32 pages in nvme
  - request split in scheduler
- or multiple metadata pages (nvme)
  - single MD page for PRP
- or segment size >4k (nvme)

Performance

Guard tag must contain checksum

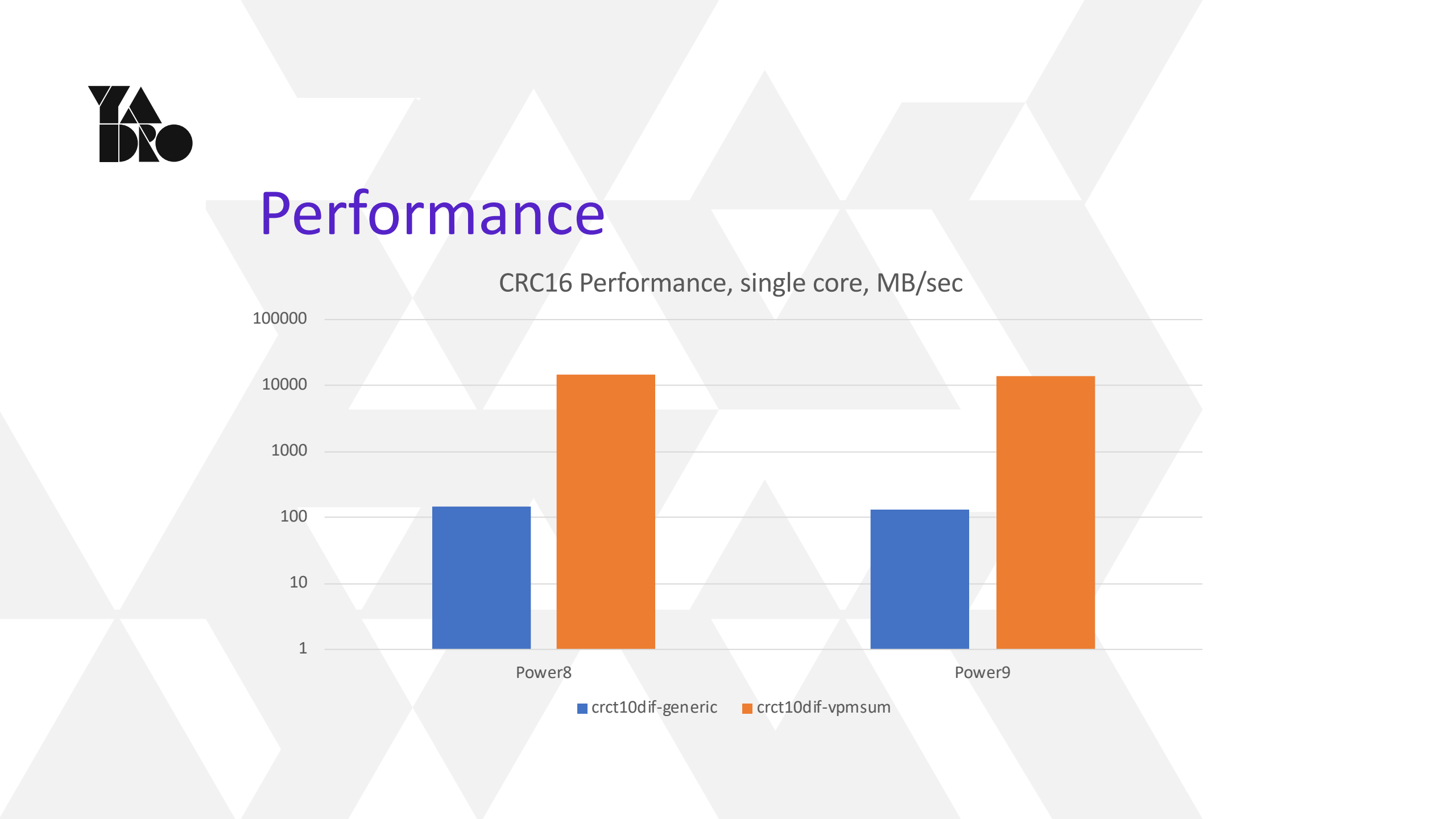
- CRC16 or IP
- NVMe supports only CRC16
- crct10dif – 200MB/s per Power8 core, alternatives:

  crct10dif-pclmul (x86_64)

  crct10dif-vpmsum 4.12+ (ppc64)

  crct10dif-arm64-neon 5.1+

  crct10dif-arm64-ce 4.10+



Performance

Summary

Works:

- T10 DIF/DIX на SCSI, NVMe PI (carefully)
- Qemu/KVM: virtio_vhost/virtio_scsi
- Device mapper (kernel 4.12+)

All above helped to deliver software with block-level integrity

Nice to have:

- NVMe PI (complex setups),
- userspace DIF API, DIF support in SPDK vhost

Questions?