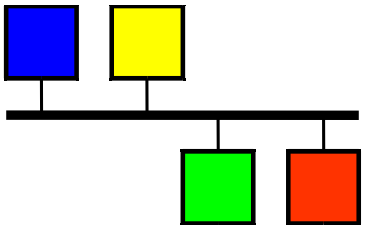

Recent Advancements and Deployments of EPICS Version 4

ICALEPCS 2015, Melbourne, Australia.

Timo Korhonen, for the EPICS Version 4 working group

Talk and paper prepared by Greg White

EPICS Version 4 Working Group

Arman Arkilic	BNL	Participant
Gabriele Carcassi	BNL	Observer
Bob Dalesio	BNL	Participant, capo di tutti i capi
Michael Davidsaver	BNL	Participant
Benjamin Franksen	HZB	Observer
Steven Hartman	ORNL	Participant
David Hickin	Diamond	Participant
Andrew Johnson	APS	Participant, co-chair
Kay Kasemir	ORNL	Participant
Timo Korhonen	ESS	Participant
Marty Kraimer	BNL	Participant
Ralph Lange	HZB	Participant
Jeong Han Lee	IBS	Participant
Nikolay Malitsky	BNL	Participant
Matej Sekornaja	Cosylab	Participant
Guobao Shen	FRIB	Participant
Kunal Shroff	BNL	Observer
Sinisa Veseli	APS	Participant
Greg White	SLAC	Participant, co-chair

GitHub (source code management) https://github.com/epics-base/
Sourceforge (documentation, admin, downloads) http://epics-pvdata.sourceforge.net

Talk Outline

- Version 4 Additions to EPICS
- Deployments
- User Feedback and Conclusions
- Recent Work

Talk Outline

- Version 4 Additions to EPICS
- Deployments
- User Feedback and Conclusions
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EPICS Version 4 in a Nutshell

- New Protocol, “pvAccess”
- Structured data
- Introspection interface, “pvData”
- Dynamic typing
- Standard Scientific Types
- RPC and putGet added
- New smart database
- Codec based transport
- All APIs in C++ and Java
- Python and Matlab
- High Performance
- High Reliability

```
$ eget -s XCOR:LI24:900:TWISS
non-normative type
structure
    double energy 5.00512
    double psix 37.7625
    double alphax 13.6562
    double betax -2.78671
    double etax -0.00698294
    double etaxp 0.00107115
    double psiy 31.9488
    double alphay 116.762
    double betay 5.2592
    double etay 0
    double etayp 0
```

Figure: pvAccess method “eget”, which is for service data, getting PV of a structure of optics parameters. In this case a standard “Normative Type” type was not used, so the raw structure is displayed by eget

The EPICS V4 “Normative Types”

The Normative Types Spec defines a standard for commonly used data types,
http://epics-pvdata.sourceforge.net/alpha/normativeTypes/normativeTypes.html

5. General Normative Types
    1. NTScalar
    2. NTScalarArray
    3. NTEnum
    4. NTMatrix
    5. NTURI
    6. NTNameValue
    7. NTTable
    8. NTAttribute
6. Specific Normative Types
    1. NTMultiChannel
    2. NTNDArray
    3. NTContinuum
    4. NTHistogram
    5. NTAggregate

```
$ eget -s XCOR:LI24:900:RMAT
     0.0727485     0.0289316             0             0     0.0652488     0.00125391
     0.0578214     0.0391775             0             0     -0.027185   -0.000192344
             0             0    0.00943029       1.14291             0               0
             0             0    -0.0013367    -0.0348832             0               0
  -0.000370971  -0.000283933             0             0    -0.0182387   -0.000198345
       0.10031      0.018722             0             0      -10.5721      -0.179568
```

```
$ eget pva://mccas0.slac.stanford.edu:39633/QUAD:LTU1:880:RMAT?type=design
```

```
$ eget -s LCLS:ELEMENTS
ELEMENT      ELEMENT_TYPE      EPICS_DEVICE_NAME     S_DISPLAY           OBSTRUCTION
CATHODE               MAD          CATH:IN20:111        2014.7                     N
 SOL1BK               MAD          SOLN:IN20:111        2014.7                     N
   CQ01               MAD          QUAD:IN20:121        2014.9                     N
   SOL1               MAD          SOLN:IN20:121        2014.9                     N
   XC00               MAD          XCOR:IN20:121        2014.9                     N
…
```

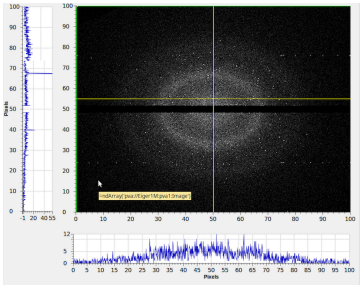
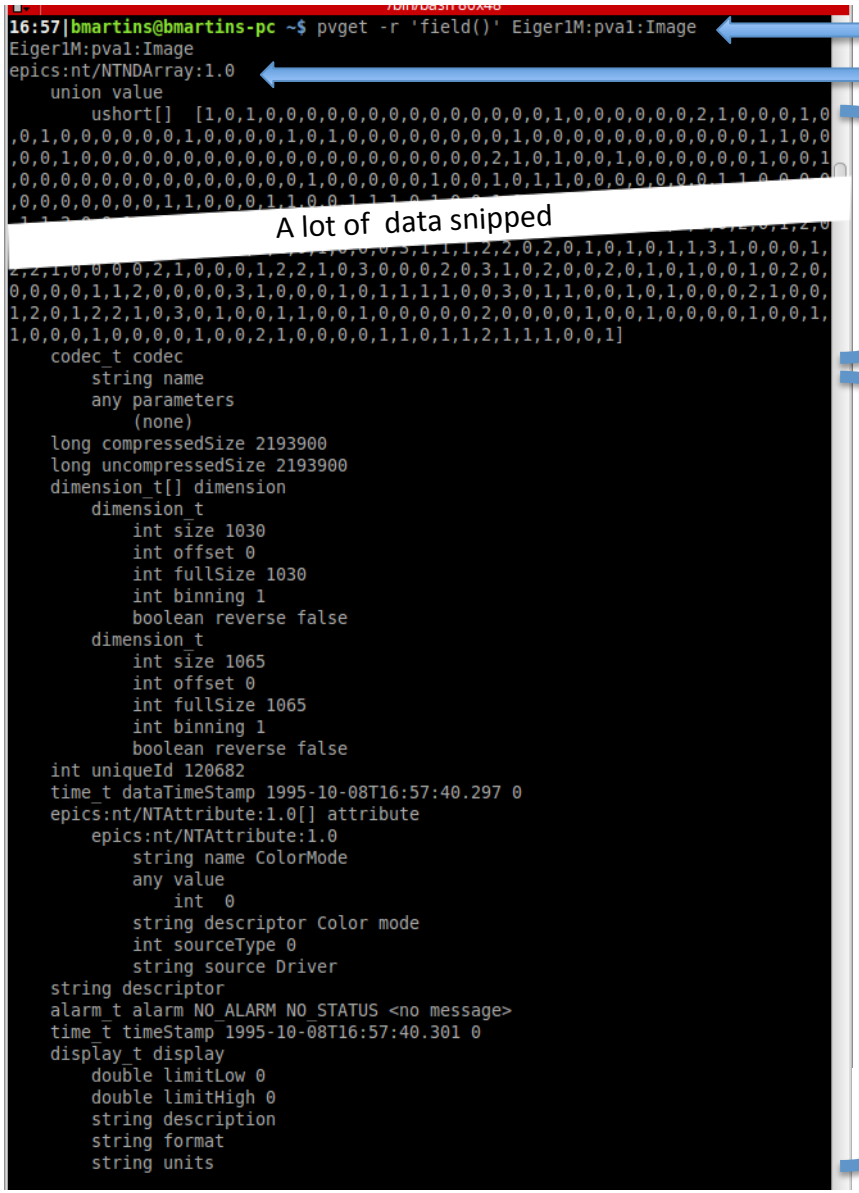


Figure: An extract of the Table of Contents of the Normative Types Specification document, together with examples of 4 selected types

What does an EPICS V4 PV for structured data look like?



The pvAccess PV name

The EPICS V4 data type identifier "NTNDArray", defined in the Normative Types Specification document

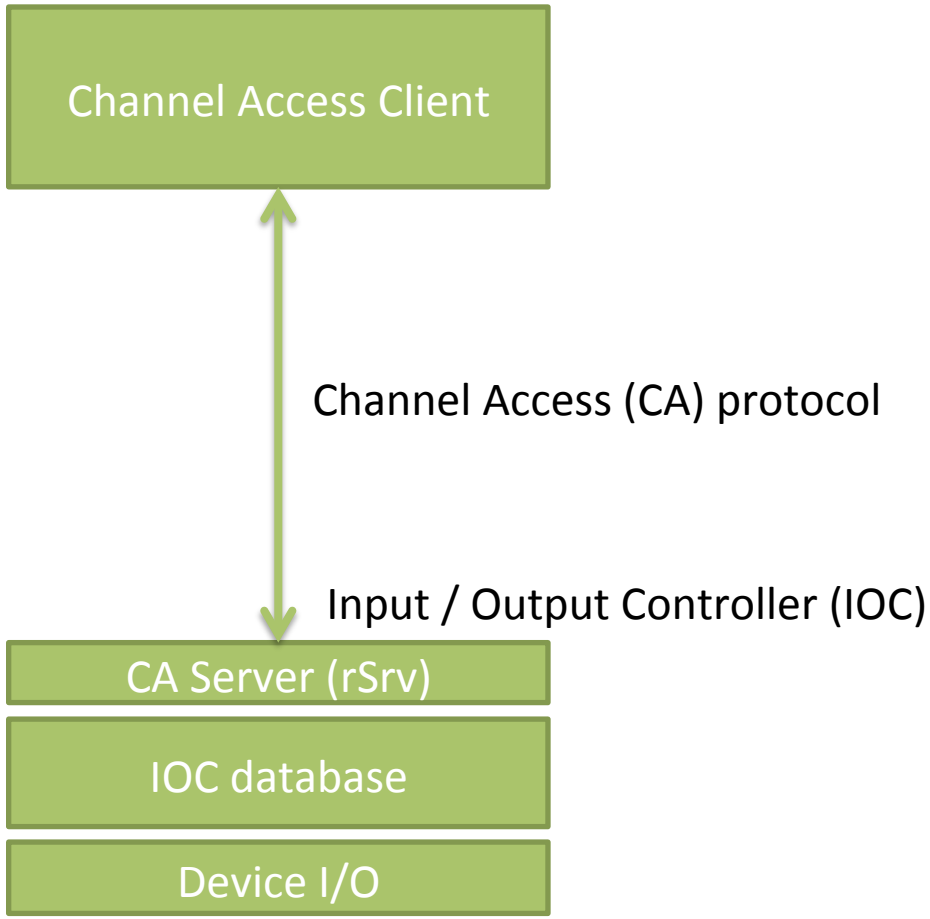
The raw image data

The image meta data; giving how to interpret the data in the *value* field, and other information.

*Figure: A screenshot of the output of the EPICS V4 "*pvget*" command, showing data of a PV which encapsulates all the data of an areaDetector NDArray (from B. Martin's AD work later in talk) in Normative Type* NTNDArray.

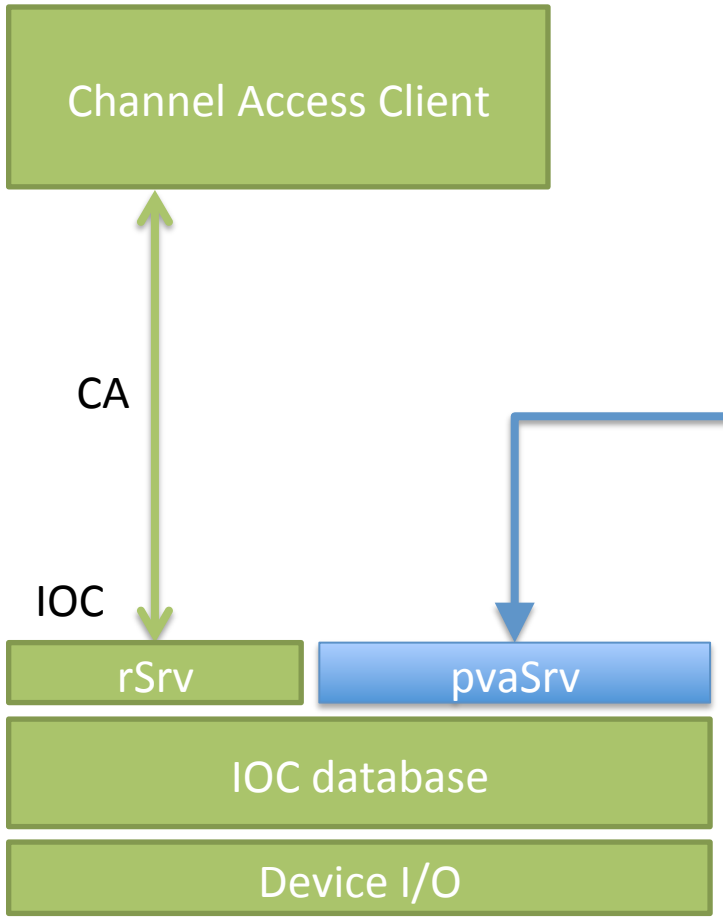
EPICS Version 3 basic block diagram

EPICS in the nominal usage: An EPICS client communicates over Channel Access (CA) protocol to an Input/Output Controller (IOC) Channel Access server (module rSrv in an IOC)



EPICS Version 4 is an extension of V3

V4 IOC == V3 IOC + pvAccess Server

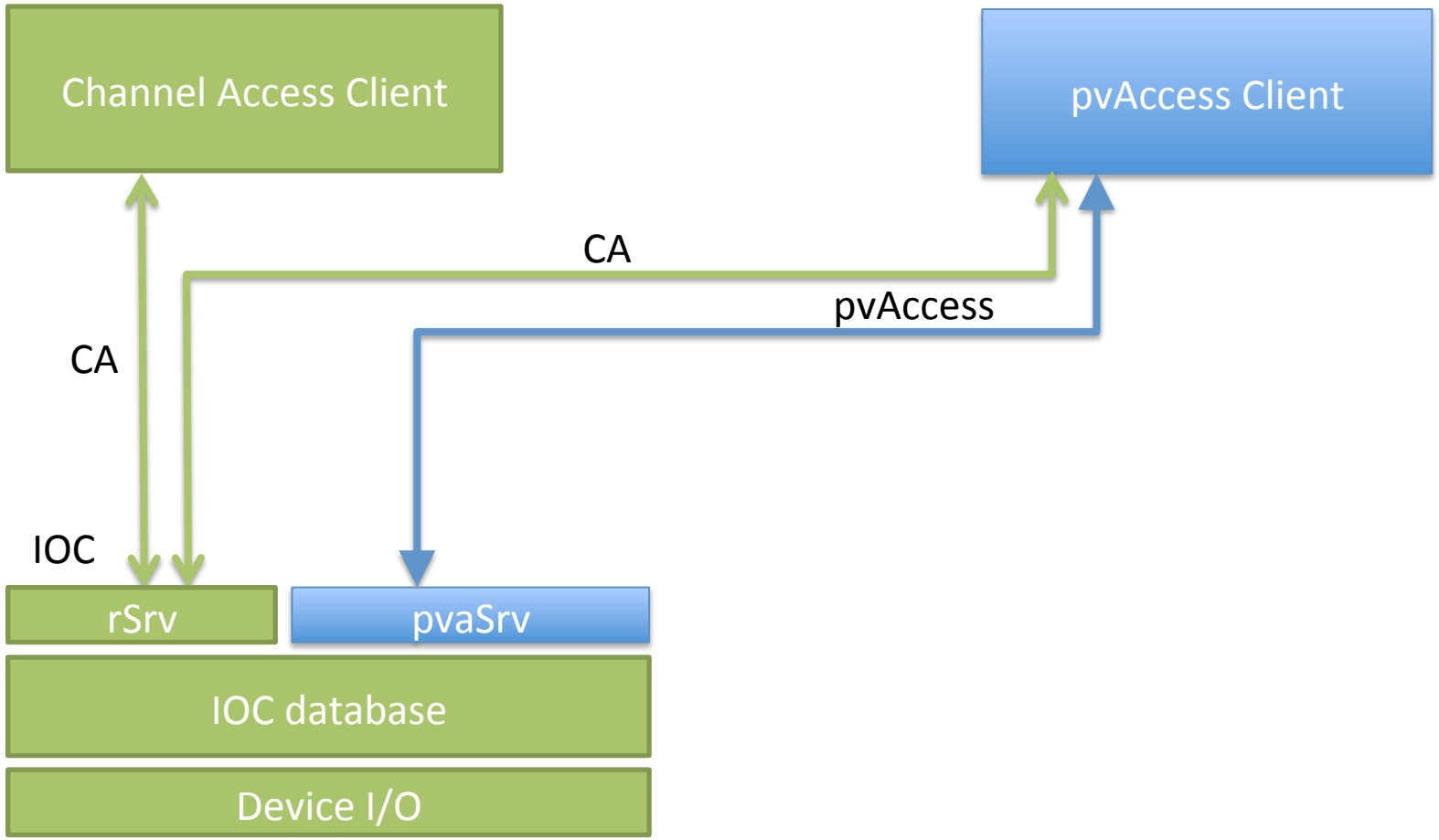


Use Case: Network efficient acquisition of archived meta data

Presently, only 1 PV per pvAccess channel. But plan is to get/monitor a group of PVs through one pvAccess channel.

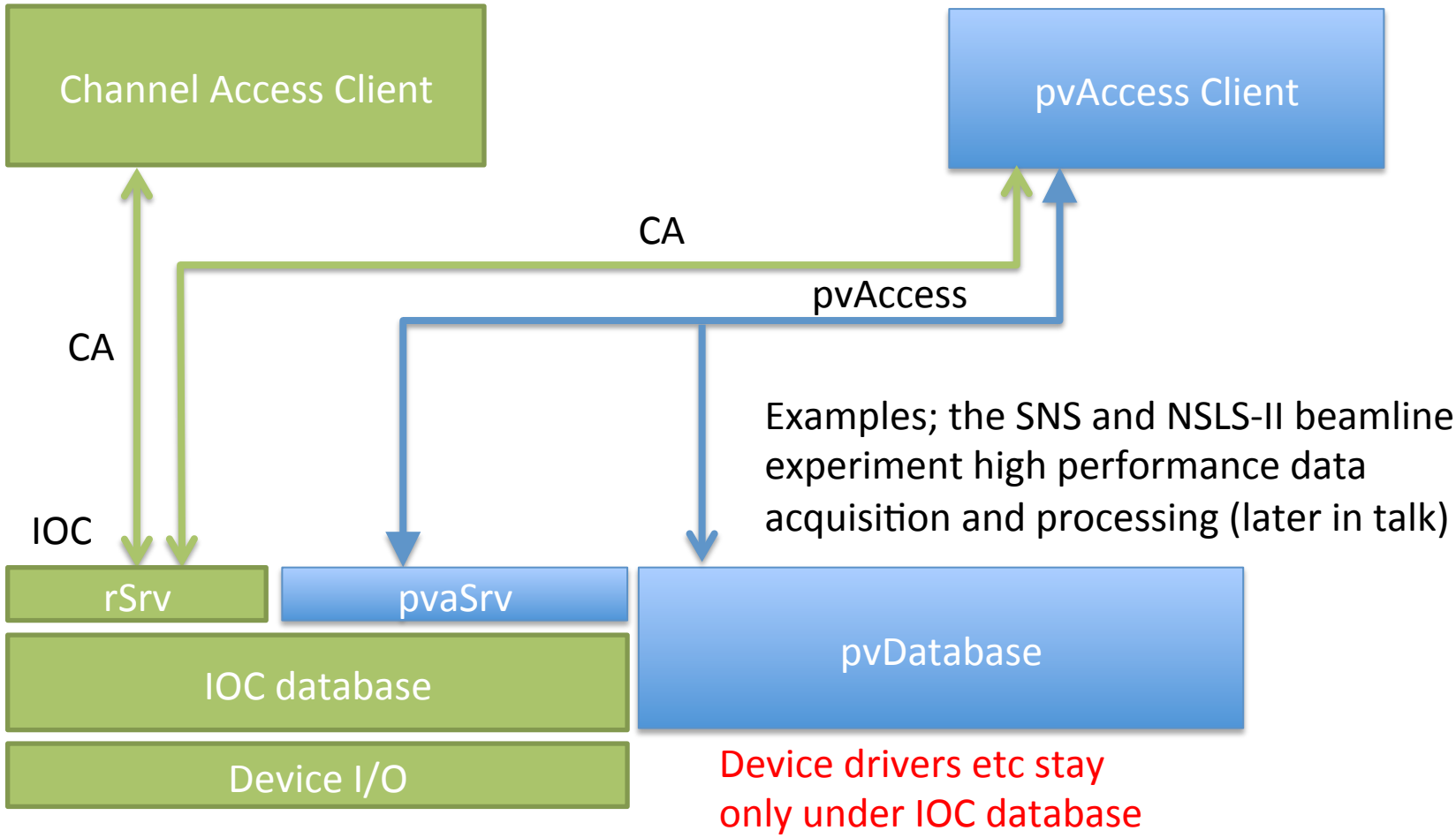
EPICS Version 4 includes CA

The pvAccess API includes Channel Access support, so one client lib does both



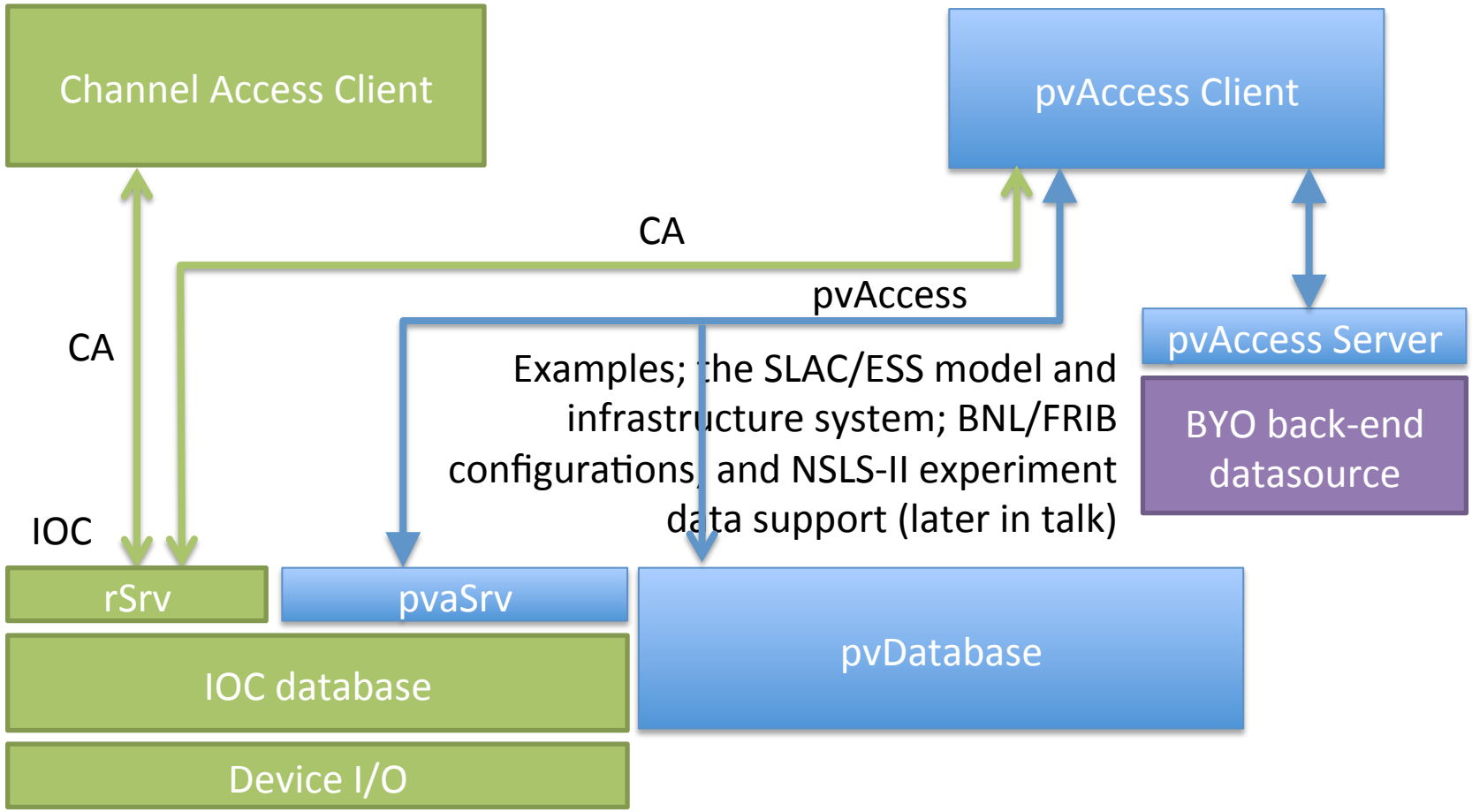
EPICS Version 4 new database

A new smart database, “pvDatabase” can be used for data assembly and processing



EPICS Version 4 middleware support

RPC and Service Oriented Architecture (SOA)



Talk Outline

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SNS uses EPICS V4 for high throughput event readout, of structured PV data.

Neutron Detector

SNS SEQUOIA detector ray consisting of >800 ^{3}He tubes covering a solid angle of 0.8 steradian

nED

- pvAccess Server
- pvDatabase
- Classic EPICS IOC

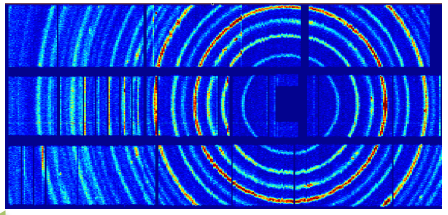
nED provides the driver interface to the detector electronics and streams experiment data using pvAccess

pvAccess streams event data at 80 Mbytes / sec

```
CHANNEL   : BL14B:Det:Neutrons
STATE     : CONNECTED
ADDRESS   : 10.111.29.150:57267
structure
    time_t timeStamp
        long secondsPastEpoch
        int nanoseconds
        int userTag
    epics:nt/NTScalar:1.0 proton_charge
        double value
    epics:nt/NTScalarArray:1.0 time_of_flight
        uint[] value
    epics:nt/NTScalarArray:1.0 pixel
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_a1
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_a2
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_a8
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_a19
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_a48
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_b1
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_b8
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_b12
        uint[] value
    epics:nt/NTScalarArray:1.0 position_index
        uint[] value
    epics:nt/NTScalarArray:1.0 position_x
        uint[] value
    epics:nt/NTScalarArray:1.0 position_y
        uint[] value
    epics:nt/NTScalarArray:1.0 photo_sum_x
        uint[] value
    epics:nt/NTScalarArray:1.0 photo_sum_y
        uint[] value
```

The V4 data structure includes an array of pixels and a corresponding array of times of flight for each recorded neutron event. Additional fields record accelerator pulse information and detector diagnostic information

CS-Studio



Diffraction rings of a powder sample at SEQUOIA, histogram generated by ADnED and displayed in CS-Studio

ADnED

- CA Server
- areaDetector data processing
- pvAccess Client

ADnED, a pvAccess client, generates online histograms and counting statistics from the nED data stream and serves them using the CA protocol to clients including CS-Studio

Kay Kasemir, Steven Hartman, ORNL

SNS's use of EPICS V4 for transport of beamline neutron event data

SNS' Conclusions:

Five beam lines currently using EPICS V4

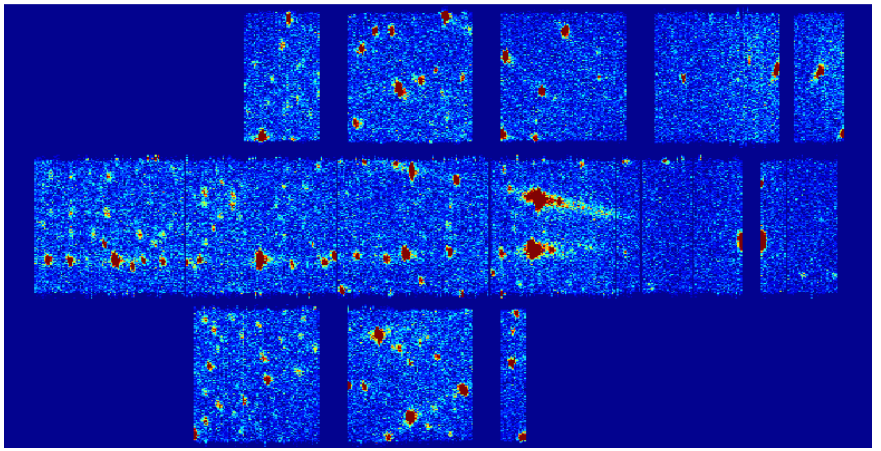
Plans to extend to all experiment beam lines.

Additionally, A pvaPy-based V4 client is used for detector calibration and diagnostics.

EPICS V4 meets performance requirements for all existing SNS instruments

Demonstrated at data rates of 10M events per second

Excellent reliability.



ADnED plot of a diffraction pattern from neutron scattering of a single-crystal sample at SNS CORELLI

```
CHANNEL   : BL14B:Det:Neutrons
STATE     : CONNECTED
ADDRESS   : 10.111.29.150:57267
structure
    time_t timeStamp
        long secondsPastEpoch
        int nanoseconds
        int userTag
    epics:nt/NTScalar:1.0 proton_charge
        double value
    epics:nt/NTScalarArray:1.0 time_of_flight
        uint[] value
    epics:nt/NTScalarArray:1.0 pixel
        uint[] value
```

Fragment of the SNS' EPICS v4 structure used for streaming experiment data at the 60 Hz rate of the pulsed neutron source

Kay Kasemir, Steven Hartman, ORNL

NSLS-II areaDetector EPICS V4 support

Problem: Modern detector rates

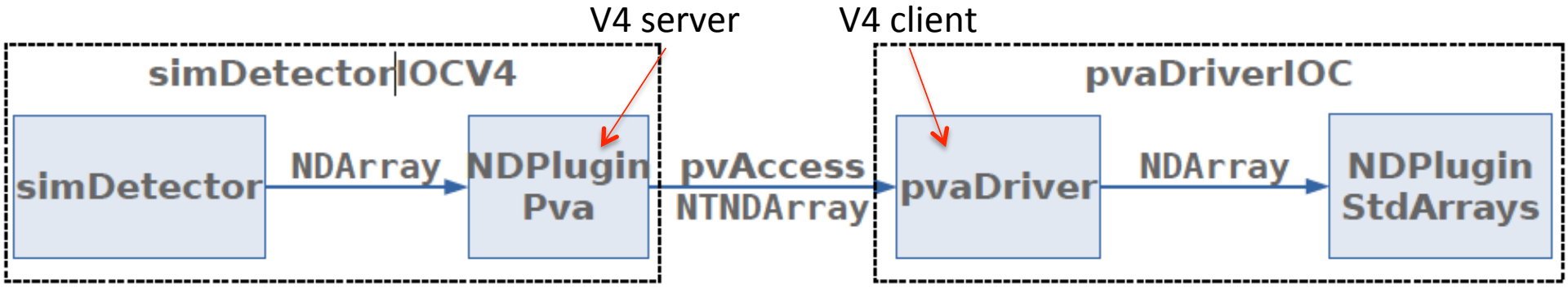
- Eiger 1M: 1030x1065 @ 3 kHz
- Eiger 4M: 2070x2167 @ 750 Hz
- Eiger 9M: 3110x3269 @ 238 Hz
- Eiger 16M: 4150x4371 @ 133 Hz

- All these detector configurations saturate a 10 Gbps link
- Other non-EPICS methods tried and failed (HTTP-chunking).

NSLS-II v4 Solution:

V4 server is an areaDetector plugin, NDPluginPva. V4 client is areaDetector driver.

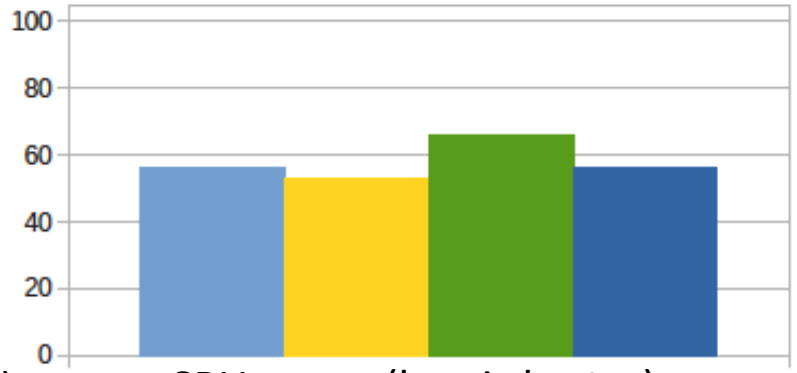
Architecture tested with SimDetector datasource:



NSLS-II V4 areaDetector Performance Test

Test simDetecor datasource 5K x 5K @ 50Hz ~= 10 Gb/s over 10Gig Ethernet.
Non-blocking callbacks. AD ImageMode: Multiple. NumImages:10000

Frames through (%) (more is better)



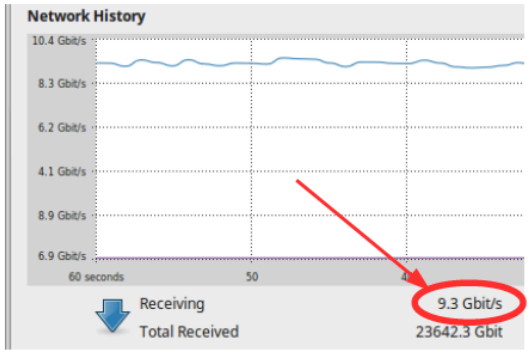
CPU usage (less is better)

Test pipeline stage

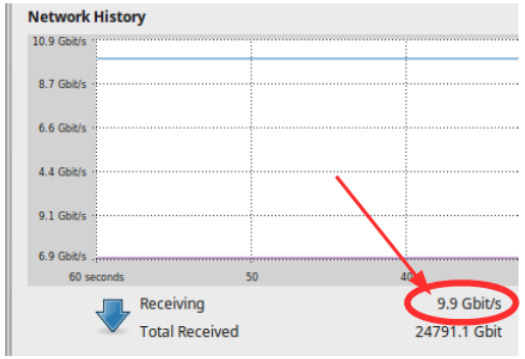
- simDetectorIOC - driver
- simDetectorIOC - plugin
- pvaDriverIOC - driver
- pvaDriverIOC - plugin

Transfer bandwidth: EPICS V4 & practical limit:

NDPvaPlugin + pvaDriver: **9.3 Gbps**

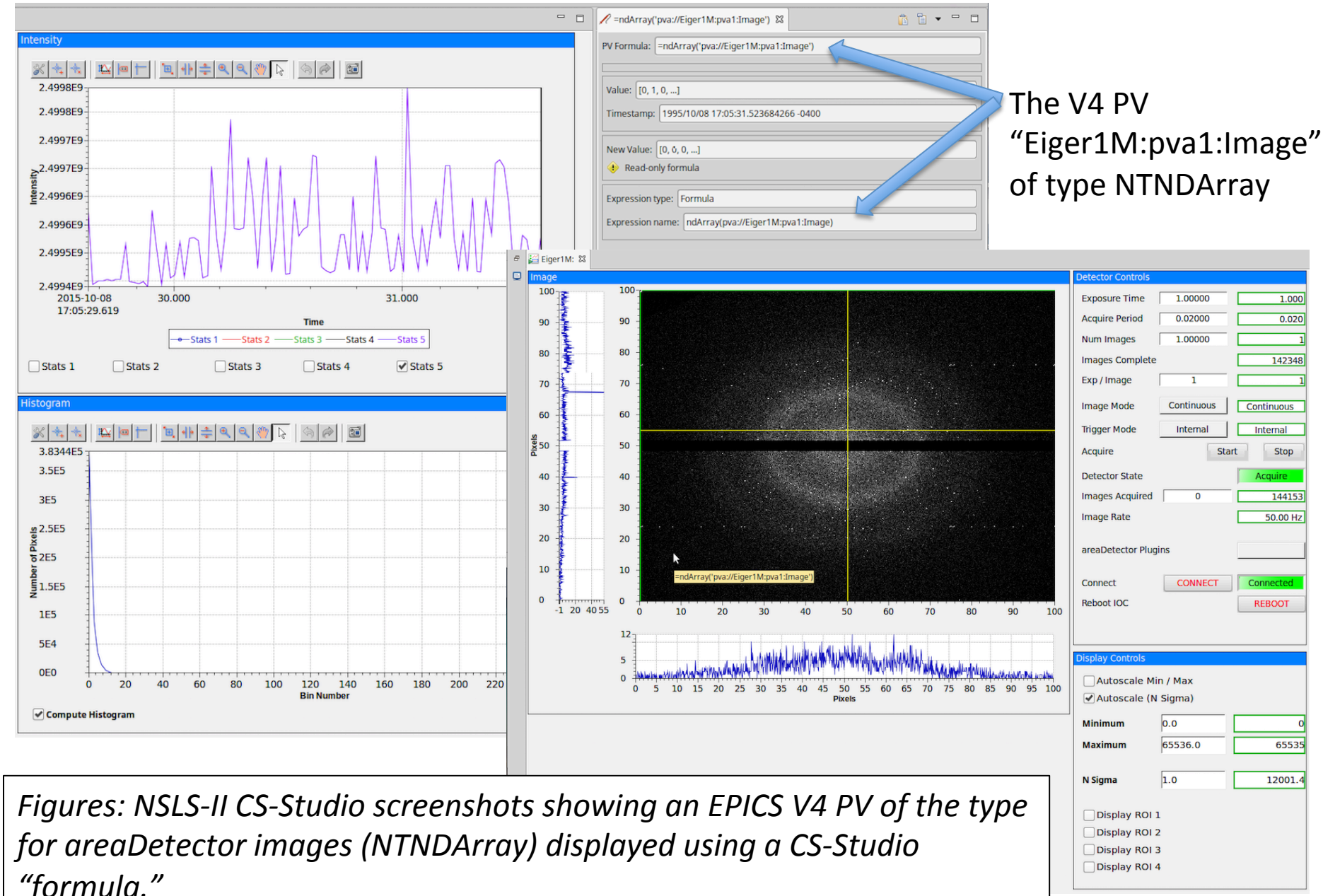


Baseline (iperf network tool): **9.9 Gbps**



NSLS-II Conclusions:
EPICS V4 based areaDetector pipeline has high throughput, few frames lost, with no CPU saturation. Network bandwidth is close the practical maximum.

Bruno Martins, BNL (following work by James Rowland and Dave Hickin at Diamond)



The V4 PV "Eiger1M:pva1:Image" of type NTNDArray

Figures: NSLS-II CS-Studio screenshots showing an EPICS V4 PV of the type for areaDetector images (NTNDArray) displayed using a CS-Studio "formula."

NSLS-II use EPICS V4 for Beamline Data Management

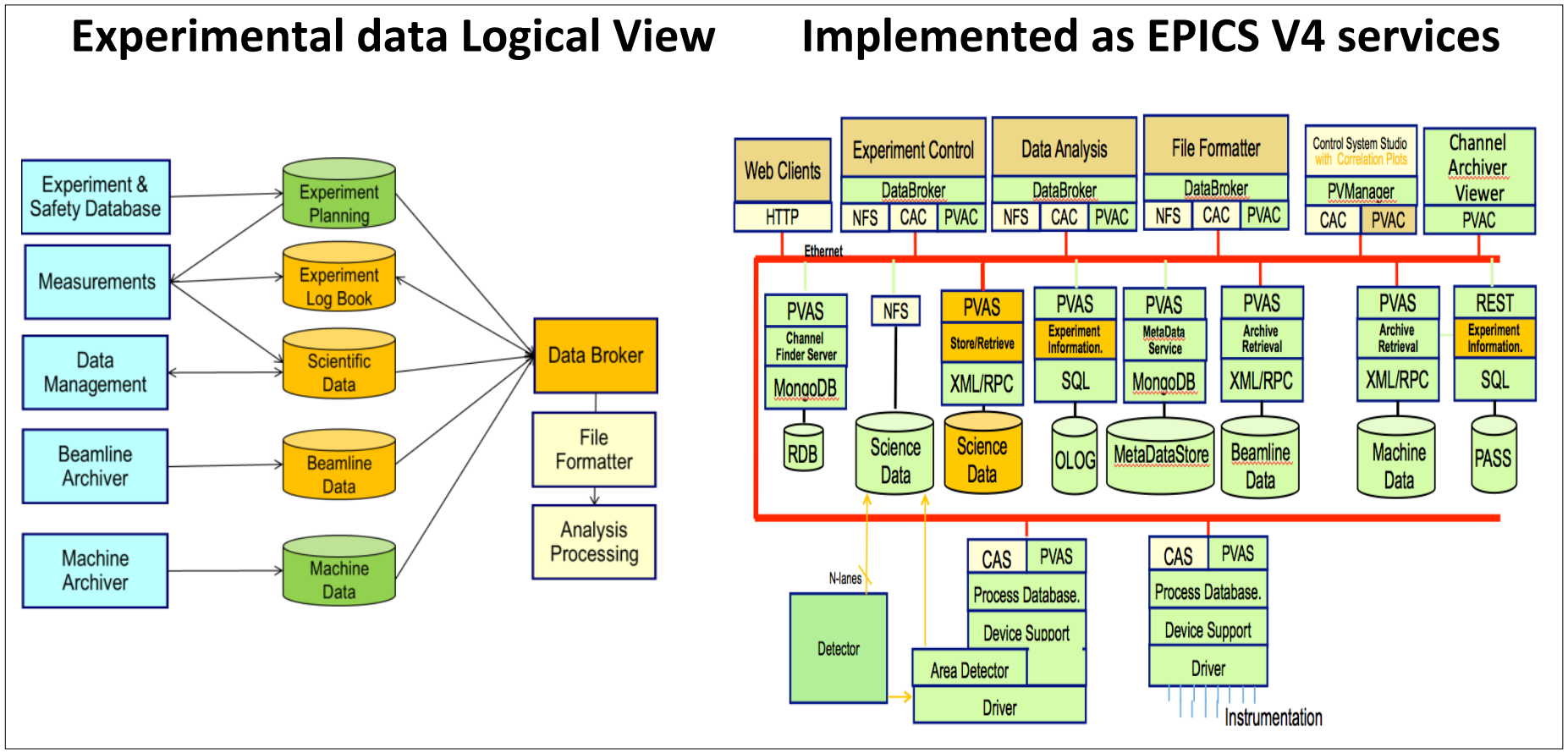
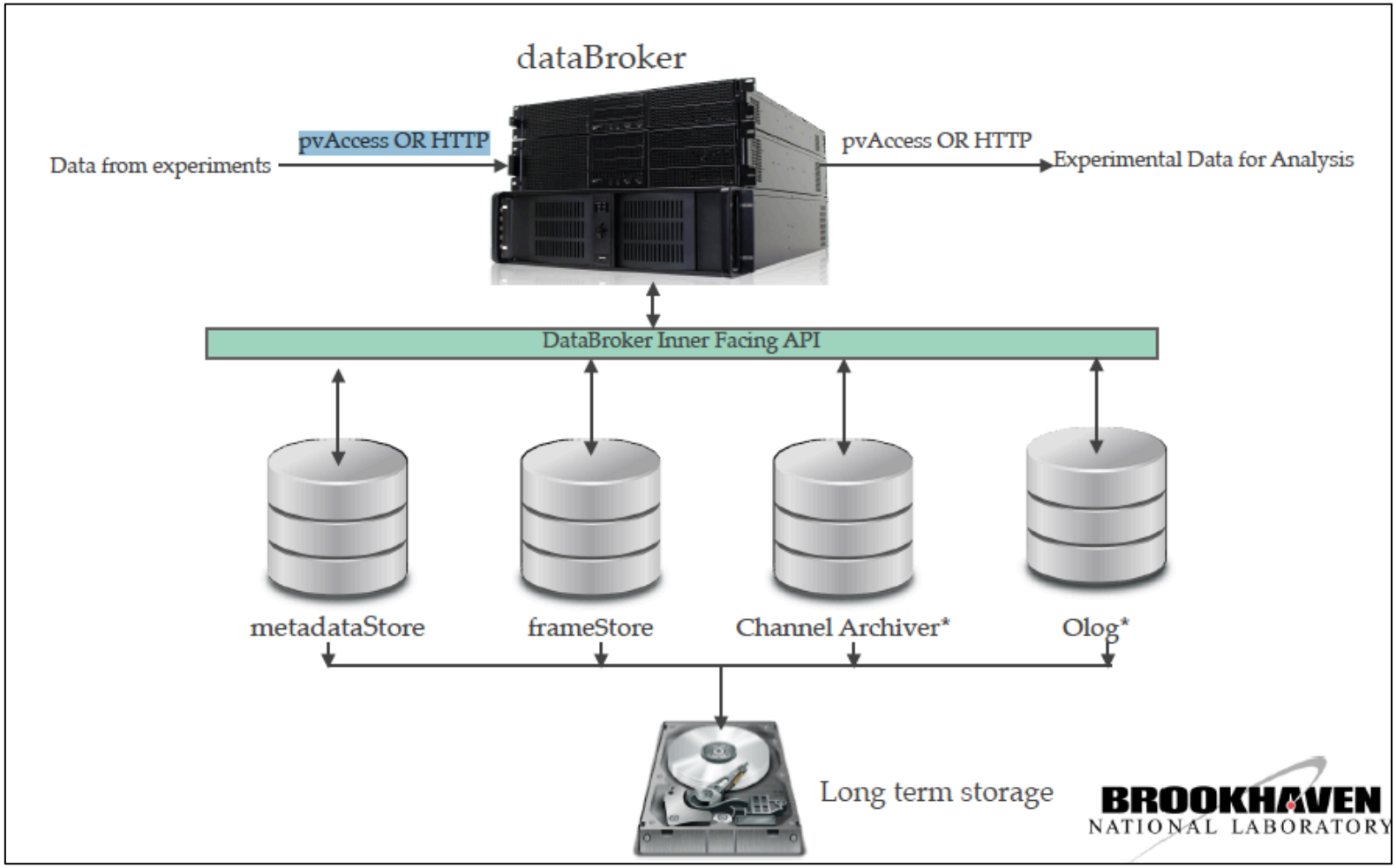


Figure: Services with thin, configurable, interfaces allow a small system of services to satisfy diverse requirements of many beamline experiments

Arman Arkilic BNL, Michael Davidsaver then at, BNL

An EPICS V4 server mediates all experiment data



"DataBroker" gives access to all data, from all services, over pvAccess or HTTP.

Arman Arkilic BNL, Michael Davidsaver then at, BNL

EPICS V4 Normative Type (NTTable) Examples from NSLS-II metaDataStore

NSLS-II beamline “run-start” metadata

```
epics:nt/NTTable:1.0
    string[] labels []
    structure value
        string[] _id [553ce3af7368e3176b472061]
        string[] animal []
        double[] arman []
        boolean[] beamline_config []
        string[] beamline_config_id []
        string[] beamline_id [xf23id]
        boolean[] config []
        string[] config.beamline_id []
        boolean[] config.custom []
        string[] config.group []
        string[] config.owner []
        string[] config.project []
        double[] config.scan_id []
        double[] config.time []
        string[] config.uid []
        boolean[] custom []
        string[] group []
        boolean[] jupiter [false]
        string[] mood []
        string[] owner [xf23id1]
        string[] plotx [pgm_energy]
        boolean[] ploty []
        string[] project []
        boolean[] sample []
        double[] scan_id [10637]
        boolean[] threading []
        double[] time [1.43005e+09]
        boolean[] time_as_datetime []
        string[] uid [f9a83f88-2d14-469c-9bce-7607e3dbfc83]
        string[] user []
```

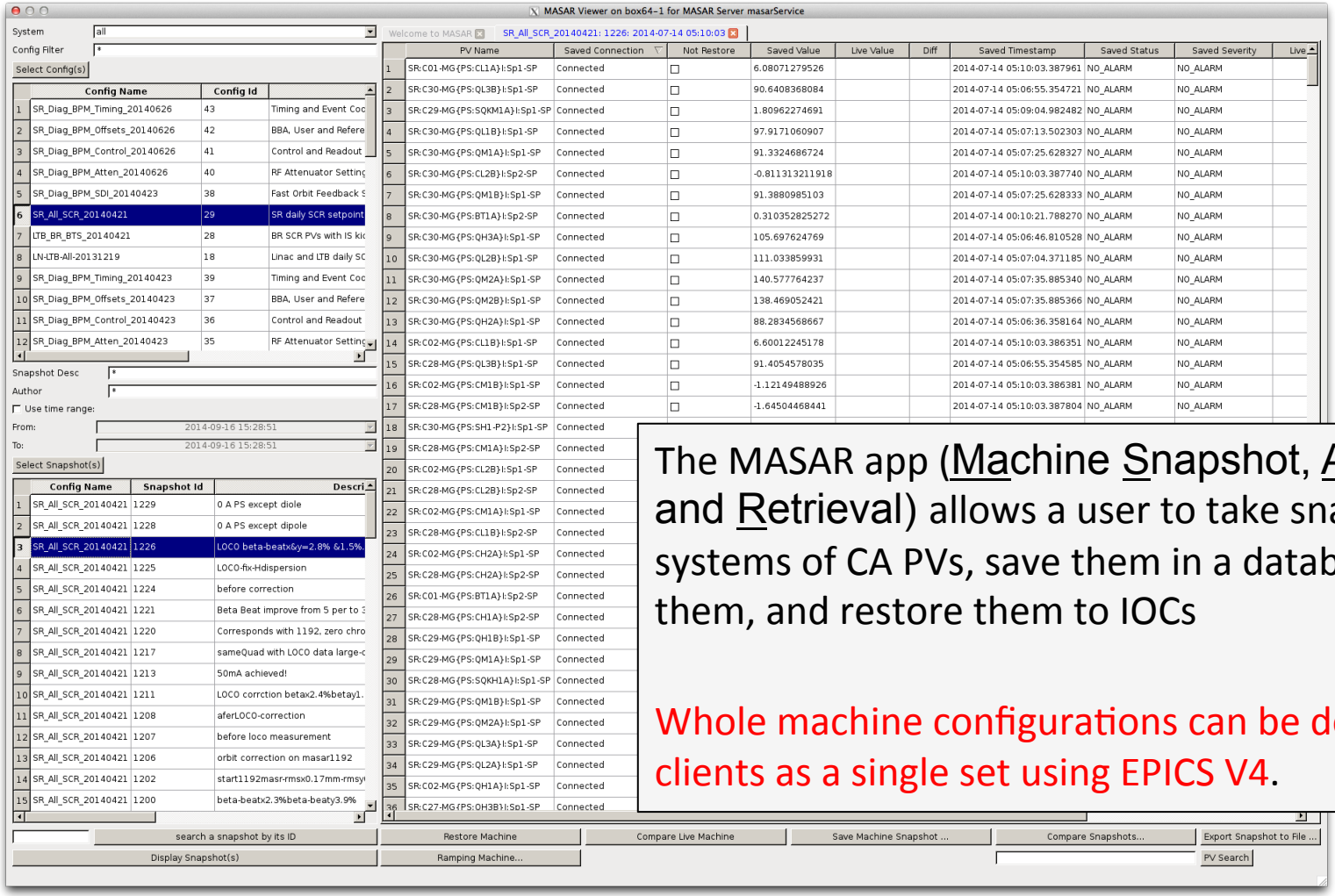
NSLS-II beamline “run-stop” metadata

```
epics:nt/NTTable:1.0
    string[] labels []
    structure value
        string[] _id []
        string[] exit_status [success]
        string[] reason [Path /GPFS/xf23id/xf23id1/fccd_data/2015/6/21/b/ does not exits on IOC!! Please
 Check]
        string[] run_start_id []
        double[] time [1.4412e+09]
        boolean[] time_as_datetime []
        string[] uid [a1bc88d4-1599-4e0f-958f-74edeb16c9dc]
```

Figure: Beamline experiment meta-data expressed in EPICS V4 Normative Type NTTable, as returned by EPICS V4 service dataBroker from data in metaDataStore.

Arman Arkilic BNL, Michael Davidsaver then at, BNL

BNL and FRIB use EPICS V4 for PV configuration management



The MASAR app (Machine Snapshot, Archiving, and Retrieval) allows a user to take snapshots of systems of CA PVs, save them in a database, view them, and restore them to IOCs

Whole machine configurations can be delivered to clients as a single set using EPICS V4.

MASAR Architecture

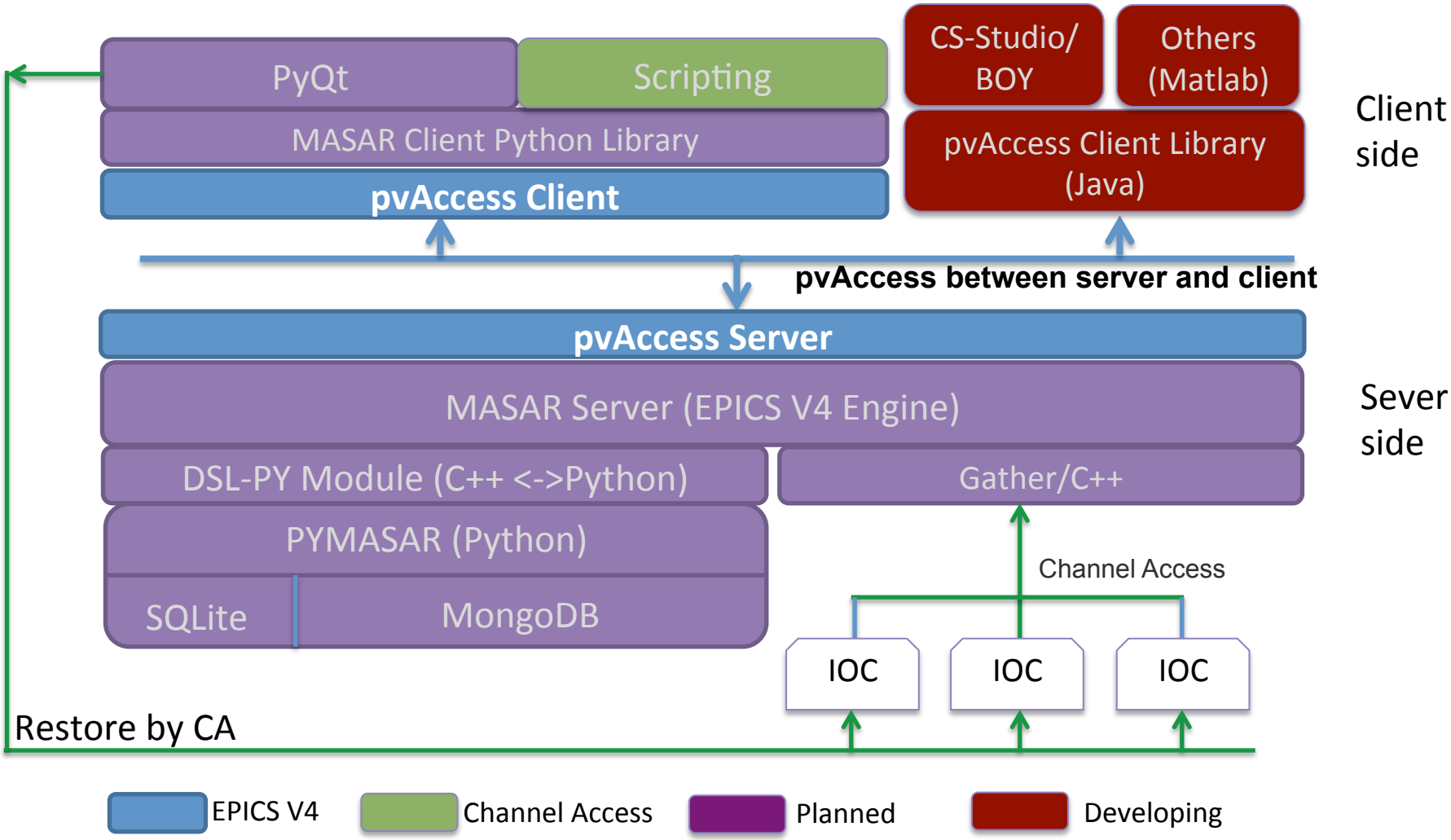
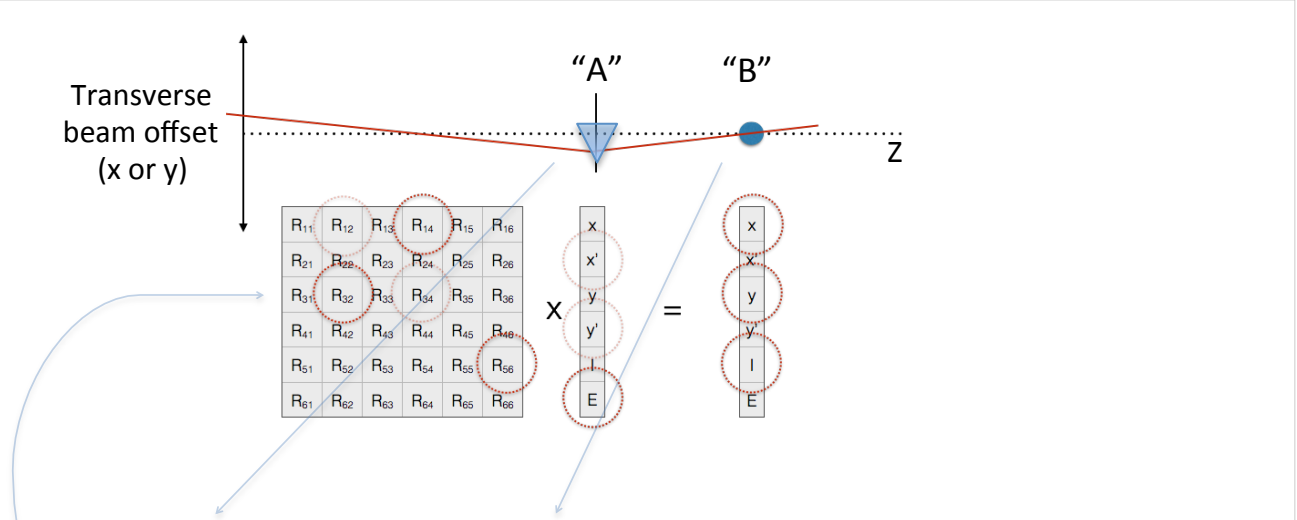
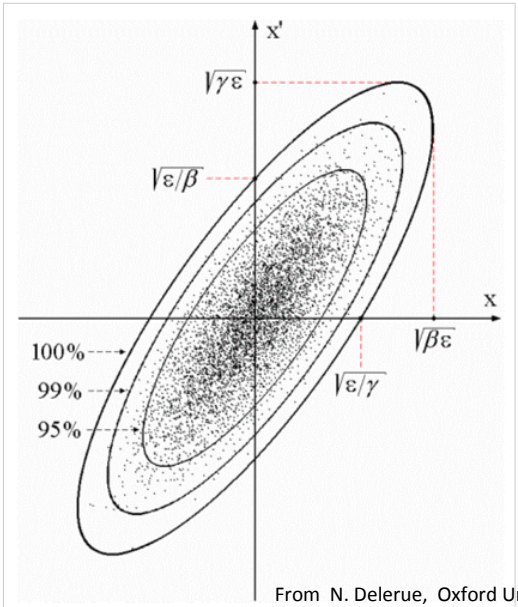


Figure : MASAR server side delivers CA PV configurations using EPICS V4, to various client types.

SLAC and ESS collaboration on EPICS V4 for beam dynamics modelling and infrastructure data




```
$ eget -s XCOR:IN20:491:RMAT -a b BPMS:IN20:525
      0.669591       0.694604              0              0  -3.08532e-19   2.41325e-19
     -0.570851       0.901275              0              0  -1.23627e-19   1.45491e-19
             0              0        1.33379       0.966896              0             0
             0              0       0.358415        1.00957              0             0
  -2.29302e-24   8.92892e-20              0              0              1   1.20724e-05
   1.00974e-28              0              0              0              0             1
```



From N. Delerue, Oxford Univ.

```
$ eget -s XCOR:LI24:900:TWISS
     energy 5.00512
     psix 37.7625
     alphax 13.6562
     betax -2.78671
     etax -0.00698294
     etaxp 0.00107115
     psiy 31.9488
     alphay 116.762
     betay 5.2592
     etay 0
     etayp 0
     z 2438.72
```

Figures: EPICS V4 modelling service giving orbit response matrices and Twiss parameters for given devices. These are the basis of 90% of emittance minimization applications – feedback, steering, bumps, etc

Greg White, Murali Shankar SLAC; Ivo List, ESS

SLAC and ESS collaboration on EPICS V4 for beam dynamics modelling and infrastructure data

Directory Service (based in EPICS V4 channelFinder) examples:

```
# The names of PVs, by device name pattern:
$ eget -s ds -a name=XCOR:LI21:135:%
        name
        XCOR:LI21:135:ABORT
        XCOR:LI21:135:ACCESS
        XCOR:LI21:135:ALLFUNCGO
        XCOR:LI21:135:BACT
        XCOR:LI21:135:BACTFO
… (many rows snipped)
```

```
# Regular expression (restrict to sectors LI25-LI29)
$ eget -s ds -a regex='XCOR:LI2[5-9]:.*:BDES'
…
# Device names of the instruments in the laser heater
$ eget -s ds -a etype INST -a tag LSRHTR -a show dname
…
# A recent search for invalid data in corrector PVs
$ eget -tTs ds -a name %COR:LTU%:%:%DES | \
eget -p ca -f - | grep nan
XCOR:LTU1:558:BDES nan
XCOR:LTU1:558:IDES nan
…
```

Oracle Database example:

```
$ eget -s LCLS:ELEMENTS
ELEMENT          ELEMENT_TYPE     EPICS_DEVICE_NAME            S_DISPLAY          OBSTRUCTION
CATHODE                 MAD         CATH:IN20:111               2014.7                    N
 SOL1BK                 MAD         SOLN:IN20:111               2014.7                    N
   CQ01                 MAD         QUAD:IN20:121               2014.9                    N
   SOL1                 MAD         SOLN:IN20:121               2014.9                    N
   XC00                 MAD         XCOR:IN20:121               2014.9                    N
 ... (many rows snipped)
```

Figure: Access to Oracle gives device infrastructure, magnet calibrations, drawing names, etc.
Will be used in LCLS-II for such things as cryogenic plant system hierarchy etc.

Greg White, Murali Shankar SLAC; Ivo List, ESS

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- User Feedback and Conclusions
- Recent Work

User Feedback – what's good:

- Performance is excellent
- Reliability needs have been met or exceeded
- Easy programming and scripting, once you've got started
- Complex data and RPC enables one, simple, high performance, infrastructure across the whole controls and online scientific system. Utility of this effect previously overlooked, but in practice seen to be key
- Normative Types enable systems of narrowly defined services to be applied generally to many experiment user problems
- Streaming supports big online data processing. Beats tested alternatives in ease of use and performance.

User Feedback – what's bad

It's difficult to get started!

We are trying to address that: see especially the new Developer's Guide:
http://epics-pvdata.sourceforge.net/informative/developerGuide/developerGuide.html

But, you know, point taken!

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Recent Additions to EPICS Version 4

- High performance array management; enforced copy-on-write semantics and zero-copy. Used by HP areaDetector projects
- Union data types
- Bound and unbound arrays
- Codec based transport, pvAccess can be replaced by zeroMQ for instance
- Security plugin
- Pipelining. Used by HP areaDetector
- New Database, pvDatabase
- Simplified APIs. New easy to use API for synchronous operations
- Easy to use wrappers for introspection interfaces of Normative Types
- Python API
- Developers Guide being written

References

- The EPICS V4 website (packaged downloads, documentation etc), http://epics-pvdata.sourceforge.net
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