

# ESRF The European Synchrotron

# *Icepap*

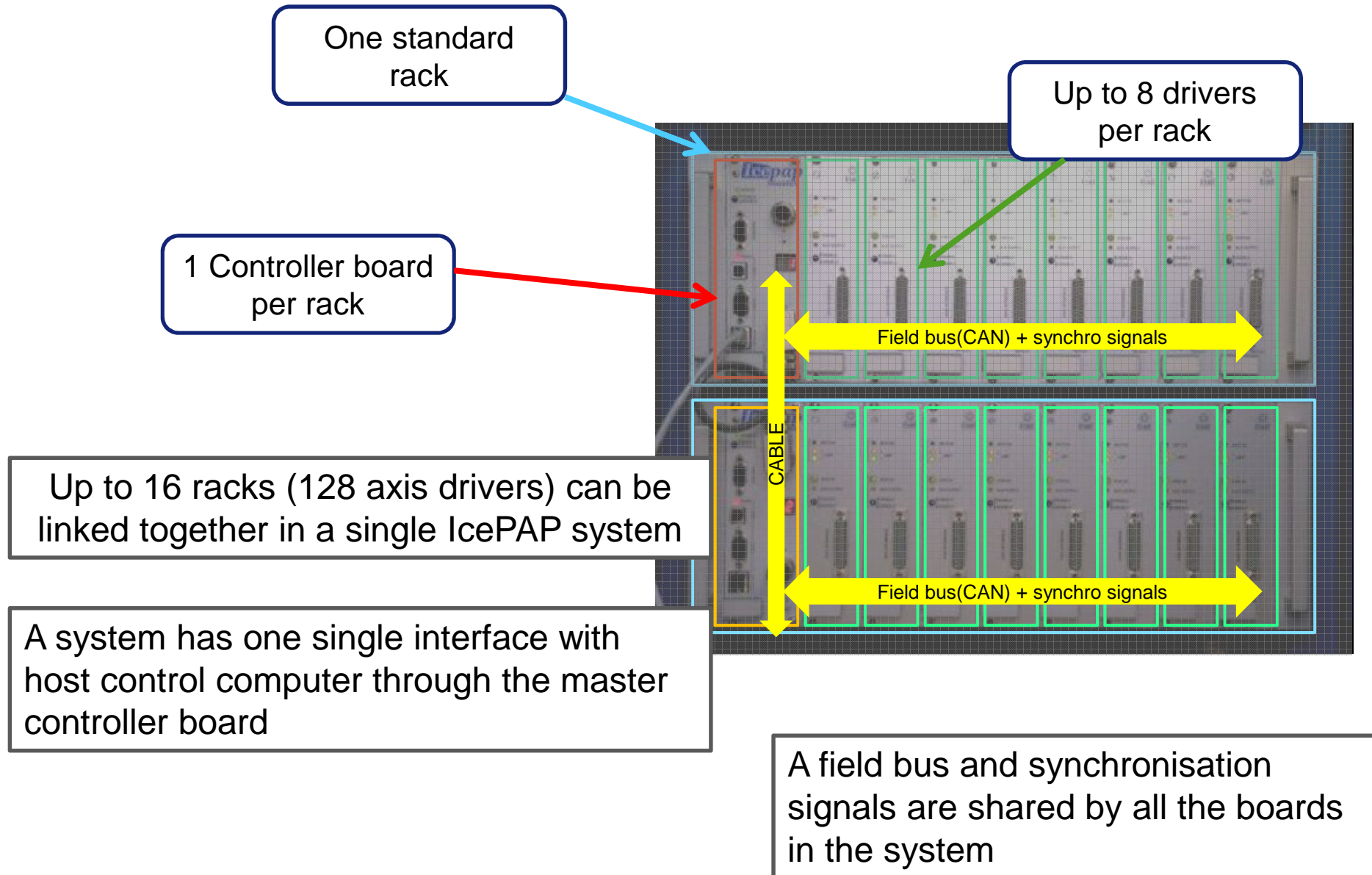
## A motion Controller

# THE ICEPAP PROJECT & COLLABORATION

- An ESRF/ALBA development collaboration
- Standard solution for steppers at ESRF, ALBA, MAX IV
  - # 6 500 axes installed
  - Collaboration agreement
    - Procurement
    - Obsolescence management
    - Development of new features



## THE ICEPAP HARDWARE: 3 MAIN COMPONENTS





## WELL SUITED TO ESRF PRESENT NEEDS



- With one single equipment, most of the motors at ESRF can be driven.
- Fully software configurable / A rich set of configuration parameters
- A high quality system with low production cost
  - > high performance: high resolution, closed loop, homing
  - > # 500 €/axis
  - > reliable

➔ One single entry point for the control Software

➔ Simple system maintenance, installation and configuration

## ICEPAP MAIN AVAILABLE FEATURES

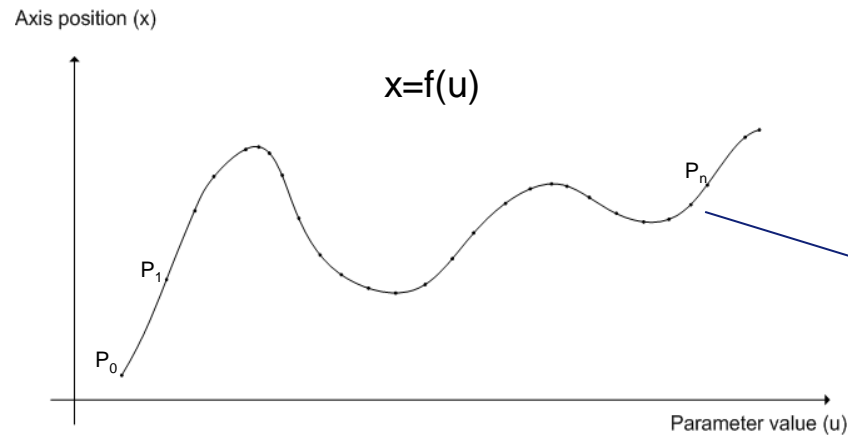
- Any 2-phase stepper motor in the 50mA to 7A current range
- Very high position resolution and high speeds (20 Msteps/s)

• T **And some advanced features, including multi-axis features, now available:**

- E
  - **Linked axes**
  - List mode movement
  - **Tracking**
  - Externally triggered motion
  - **Electronic CAM**
  - **Position signal multiplexer**
  - **Parametric trajectories**
- F
- O

- Multi-axes synchronization
- Advanced home search sequences

# PARAMETRIC TRAJECTORIES APPLICATION



A parametric table can be loaded on each driver.

$P_i \rightarrow (U_i, X_i, dX_i/du)$

- Positions of the curve between table points are interpolated (linear, or cubic splines).
- Tables can be cyclic (for periodic movements).

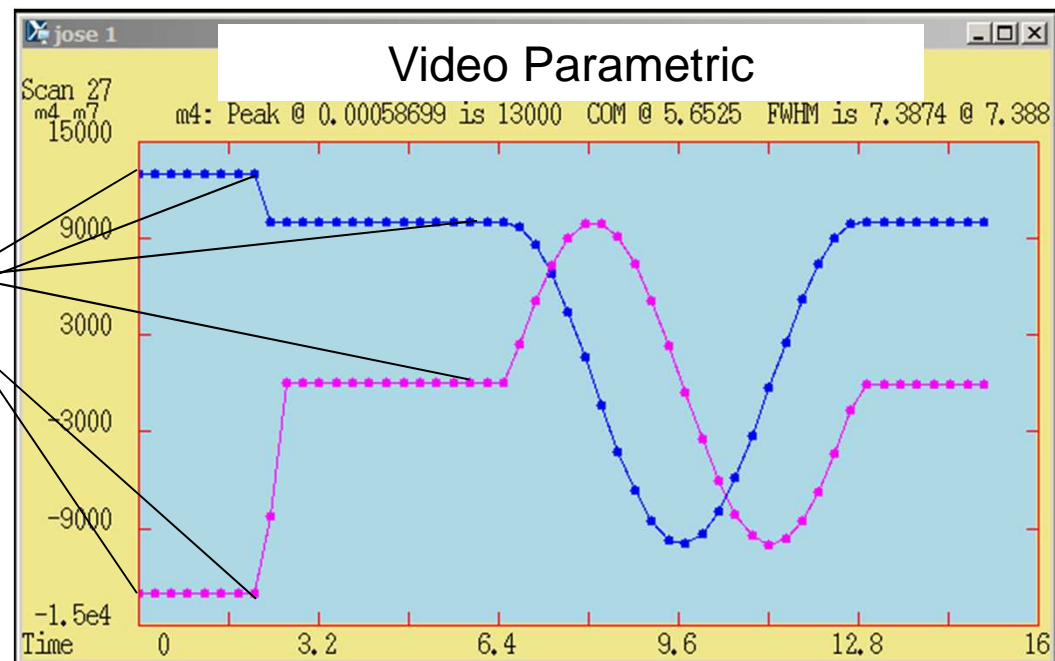
## Example with 2 axes: x, y

$$x(u) = 10000 \sin(u)$$

$$y(u) = 10000 \cos(u)$$

$$u \in [0; 2\pi]$$

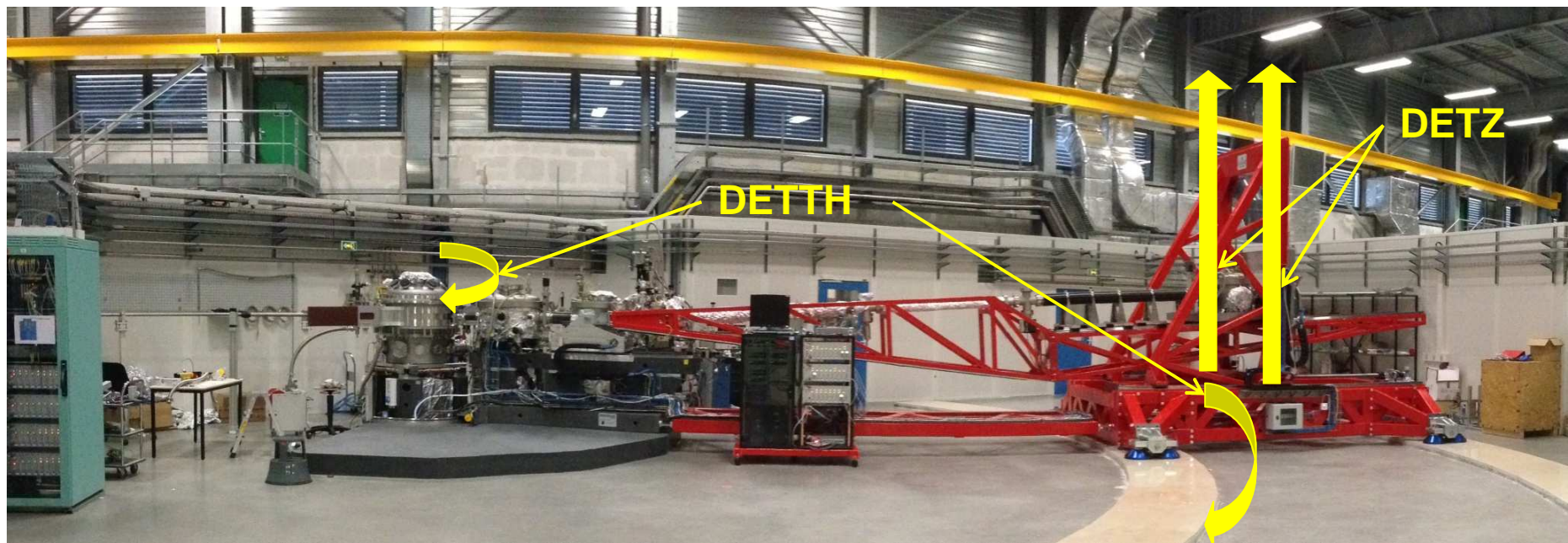
Then, both axes  
Now, both axes can  
be moved along the  
parametric curve, for  
example  $u = 6.28$   
 $x = 13000$   
 $y = -13000$   
MOVEP 0 x y



## LINKED AXES APPLICATIONS

One single degree of freedom with several physical axes: the Control host sees only one axis, defined by a configuration parameter (LNKNAME)

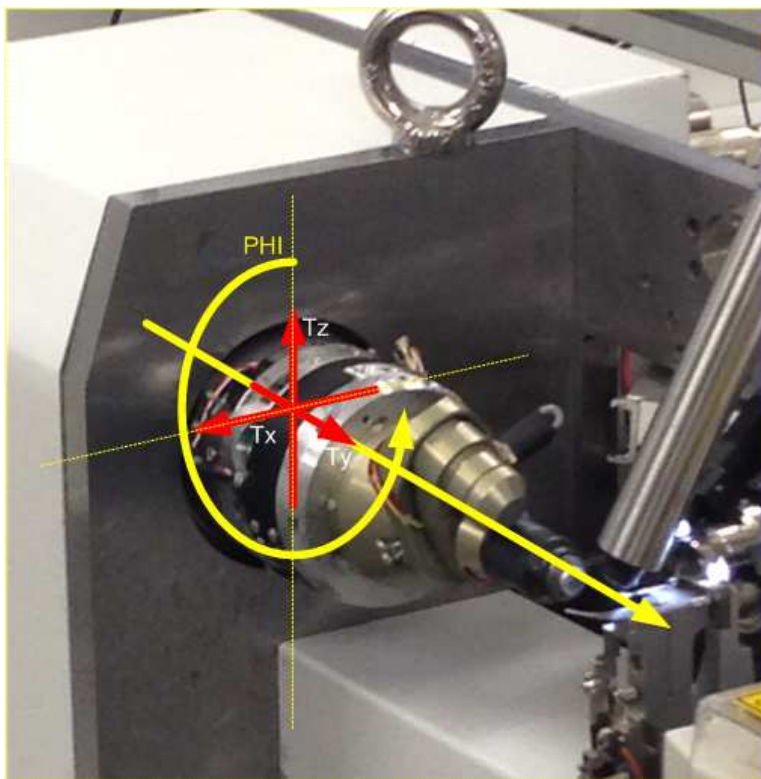
Detz and Detth in new RIXS instrument in ID32.



## EXAMPLE OF APPLICATION: HELICAL SCAN IN MX BEAMLINE ID23

### Implementation of Position Multiplexer & Tracking features

The sample crystal is rotated (PHI) and simultaneously translated in 3 perpendicular directions (X, Y, Z)



Video Helical Scan



## EXAMPLE OF APPLICATION: HELICAL SCAN IN MX BEAMLINE ID23

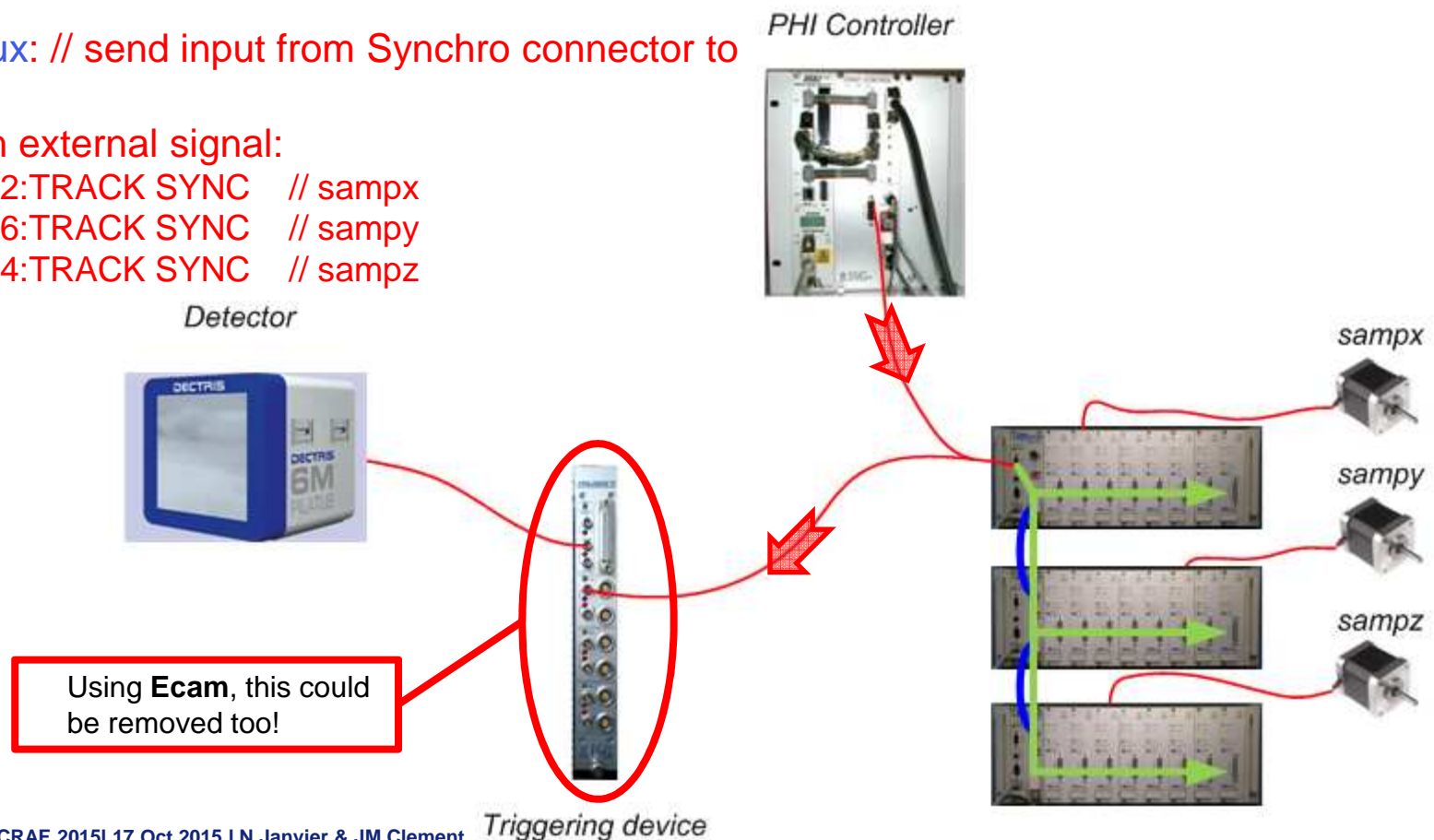
### Implementation of Position Multiplexer & Tracking features

The sample crystal is rotated (PHI) and simultaneously translated in 3 perpendicular directions (X, Y, Z)

Position mux: // send input from Synchro connector to all boards

Tracking an external signal:

2:TRACK SYNC // sampx  
16:TRACK SYNC // sampy  
24:TRACK SYNC // sampz



## ELECTRONIC CAM

A simple & useful way to synchronise detectors with axes positions without the need of any other hardware.



**A synchronisation output pulse in each driver:**

- At given position intervals: ECAMDAT <first\_pos> <last\_pos> <n\_of\_points>
- At positions predefined in a list loaded in the driver: \*ECAMDAT <bindatalist>

**Possible position sources: - internal positions - external encoders  
(incremental or absolute...)**

### Data recording (oscilloscope mode)

- Recording of positions, time, internal variables
- Configurable Internal and external triggers
- Different trigger/recording modes
- Available memory: 1MByte (to be shared with Ecamdat, Listdat, Parametric table...)

### Additional motor types

- DC brushed motors
- 3-Phase steppers
- & 3-phase synchronous and brushless motors

*Only digital encoders as shaft position sensor, no support for analog sensors (resolvers, tachometers, hall effect sensors...)*

# ACKNOWLEDGMENTS



- José-María Clement - ESRF
- Pablo Fajardo - ESRF
- Manuel Perez - ESRF
- Guifré Cuní - ALBA
- Julio Lidón - MAX IV
- ID32, ID23, ID03 & BM05 Beam line staff





# Thank you for your attention



# A motion controller

José María Clement

Instrumentation Services and Development Division

Detector & Electronics Group / Electronics Unit

01-06-2015



## THE ICEPAP MOTION CONTROLLER

1. Overview of the IcePAP system
2. Features in the last release
3. Future developments

# THE ICEPAP HARDWARE

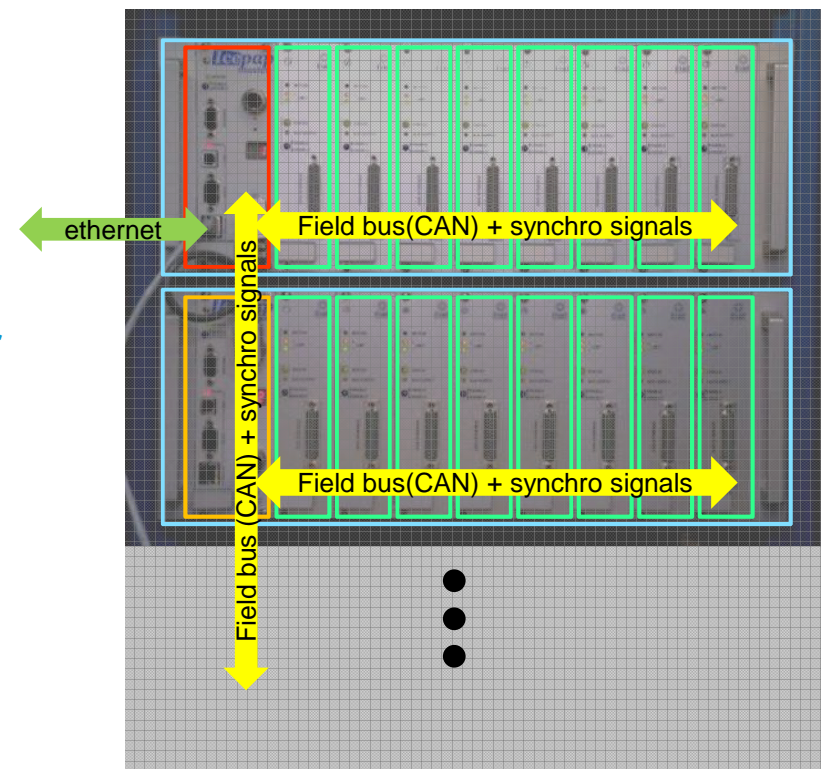
An IcePAP system is composed of 3 main hardware components:

- Standard racks
- Controller boards: one per rack
- Driver boards: up to 8 per rack

Up to 16 racks (128 axis drivers) can be linked together in a single IcePAP system

A system has one single interface with host control computer through the master controller board

A field bus and synchronisation signals are shared by all the boards in the system





# THE DRIVER BOARD

## A High performance single-axis controller

- Intelligent indexer and motor power management
  - Different types of motors
  - up to 2 encoder readout electronics
  - Non-volatile memory for configuration, settings and positions
  - All the hardware resources are accessible through the programmable chips
    - TI tms320f2812 DSP
    - Xilinx Spartan IIE FPGA (old version)/ SPARTAN 6 (new driver)
- Hardware fully configurable by software (no jumpers)
- A flexible motor power supply
    - Motor current regulation configurable
    - Motor supply voltage variable and configurable
  - Internal synchronisation signals, shared with all drivers in a system
  - External In/Out synchronisation signals on each driver



# THE CONTROLLER BOARD

## Slave boards

### Execute rack specific functions

- Initialisation of the rack drivers
- Synchronisation signals multiplexing
- Rack switches and signals management

## Master boards

- All the slave functions for its rack
- A linux CPU provides the interface between the drivers and the external control system
- Manages all the system functions
  - Axes synchronisation
  - Multiaxis management
  - System initialisation
  - System firmware upgrade



# THE ICEPAP RACK

- Provides mechanical support for the boards
- 1 kW power supply with power factor correction
- Good quality back plane connectors for motor and encoders





## ICEPAP CLASSIC FEATURES

- Any 2-phase stepper motor in the 50mA to 7A current range
- Very high position resolution and high speeds (20 Msteps/s)
- Trajectory generation:
  - Linear trajectories (point to point)
  - Jogging
  - Updated move command (no wait for stop needed)
- Encoders:
  - Readout: Incremental and SSI absolute
  - 5V, 4-wire power supply.
- Position closed loop operation
- Control encoder
- Multiaxes synchronisation
- Advanced home search sequences



# ICEPAP FIRMWARE: LAST RELEASE

**Last release (version 3.11) installed in a few beamlines since February 2015.**

**A general upgrade in all ESRF systems foreseen before summer 2015**

**A special release for MAX IV: version 3.12**

- based on version 3.11
- added support for BISSC encoders

**Firmware packages for both releases in the Download section of the Alfresco website:**

**<https://www.esrf.fr/share/page/site/IcePAPexchange/documentlibrary>**

# LINKED AXES

One single degree of freedom with several axes.

The Control PC system sees only one axis, defined by a configuration parameter (LNKNAME)

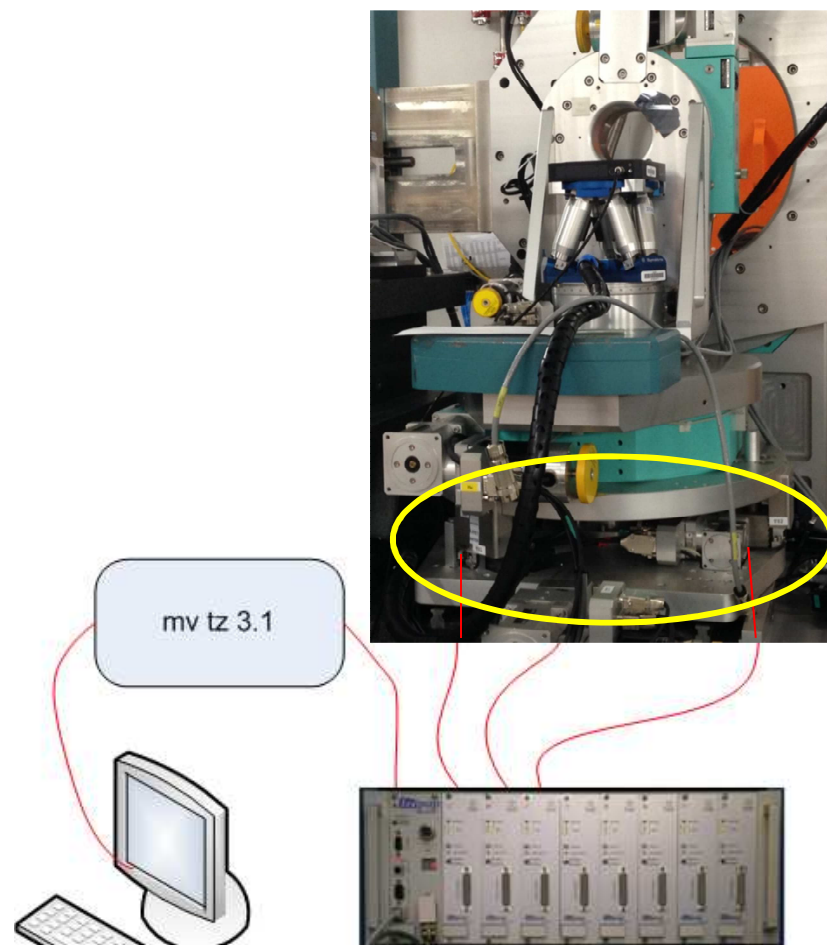
All the axes are monitored by the master controller during movements

Multiaxes stop and realignment

Only movements to LNKNAME are allowed

Special command to override protections and allow single axis movement during alignment:  
**3:DISPROT LINKED; 3:move 1000**

Jose Maria Clement. 01/06/2015



# LINKED AXES

## System aspects:

After reset, the master checks for linked axes and keeps a table

?LINKED

?LINKED

\$

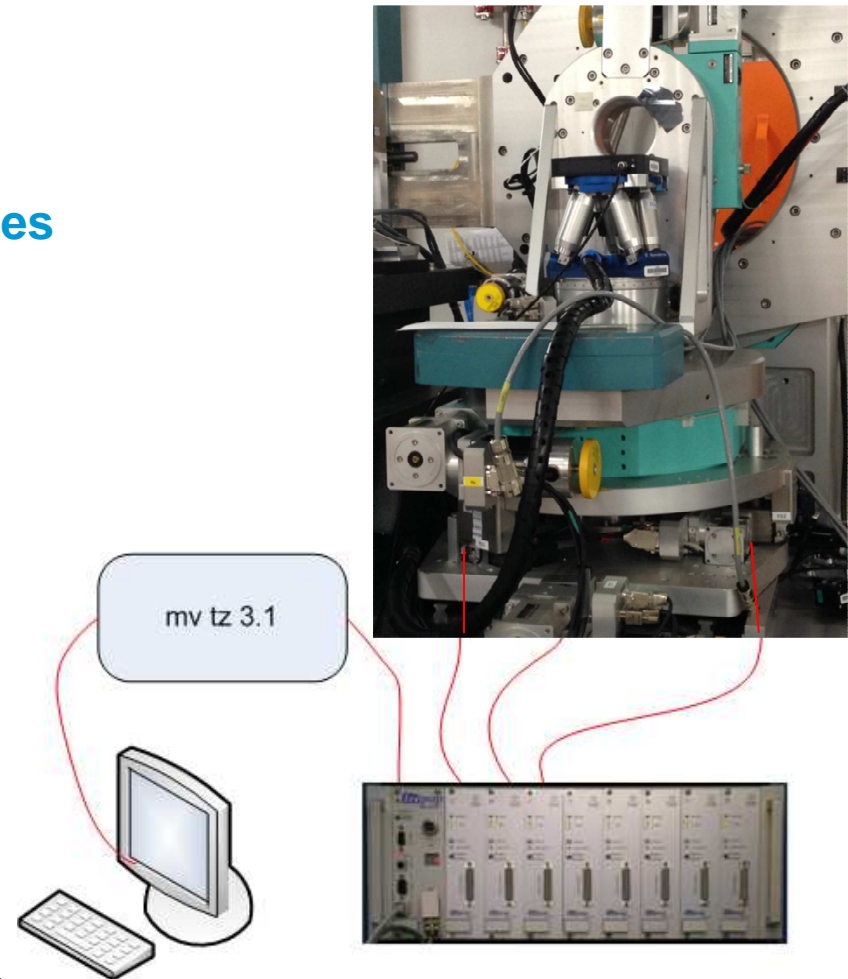
tz 1 2 3

\$

**Movement commands are not possible if velocity, acctime and position are not the same on all the real axes**

MOVE tz 100

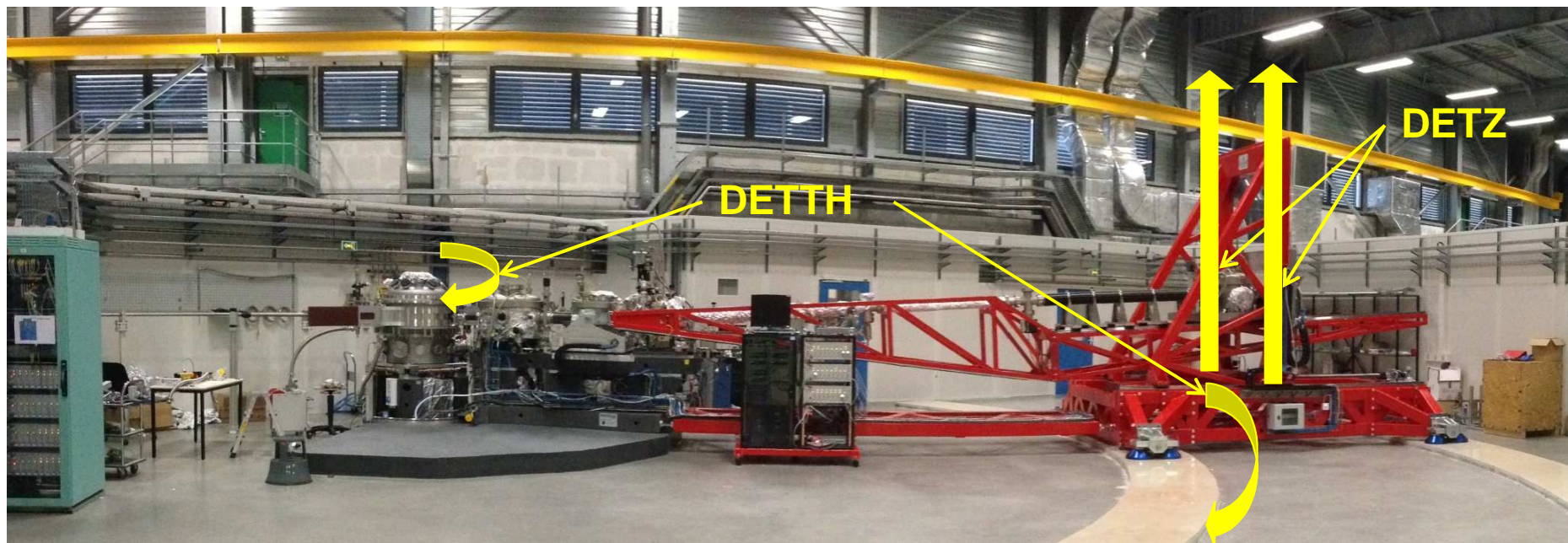
MOVE ERROR: Cannot move axis 1 in group 'tz': Linked axes are not in sync



# LINKED AXES APPLICATIONS

Two tripods in ID01, double mirror support in ID16, detector support in ID22.

Detz and Detth in new ERIXS instrument in





# LIST MODE MOVEMENTS

## List definition

A list of predefined positions can be loaded into the driver with the LISTDAT commands:

LISTDAT <startpos> <endpos> <n\_of\_points>

\*LISTDAT [dataformat] <bindata with arbitrary list of positions>

The list can be cyclic

## Movements to list positions

MOVEL N: moves the axis to the position at index=N in the list.

Parameter N is a float!! (linear interpolated positions if N is not integer)

If the list is cyclic, MOVEL to <n\_of\_points>+1 will move to position at index 0

# LIST MODE MOVEMENTS

Example:

7:LISTDAT 0 5000 6

7:MOVE1 1

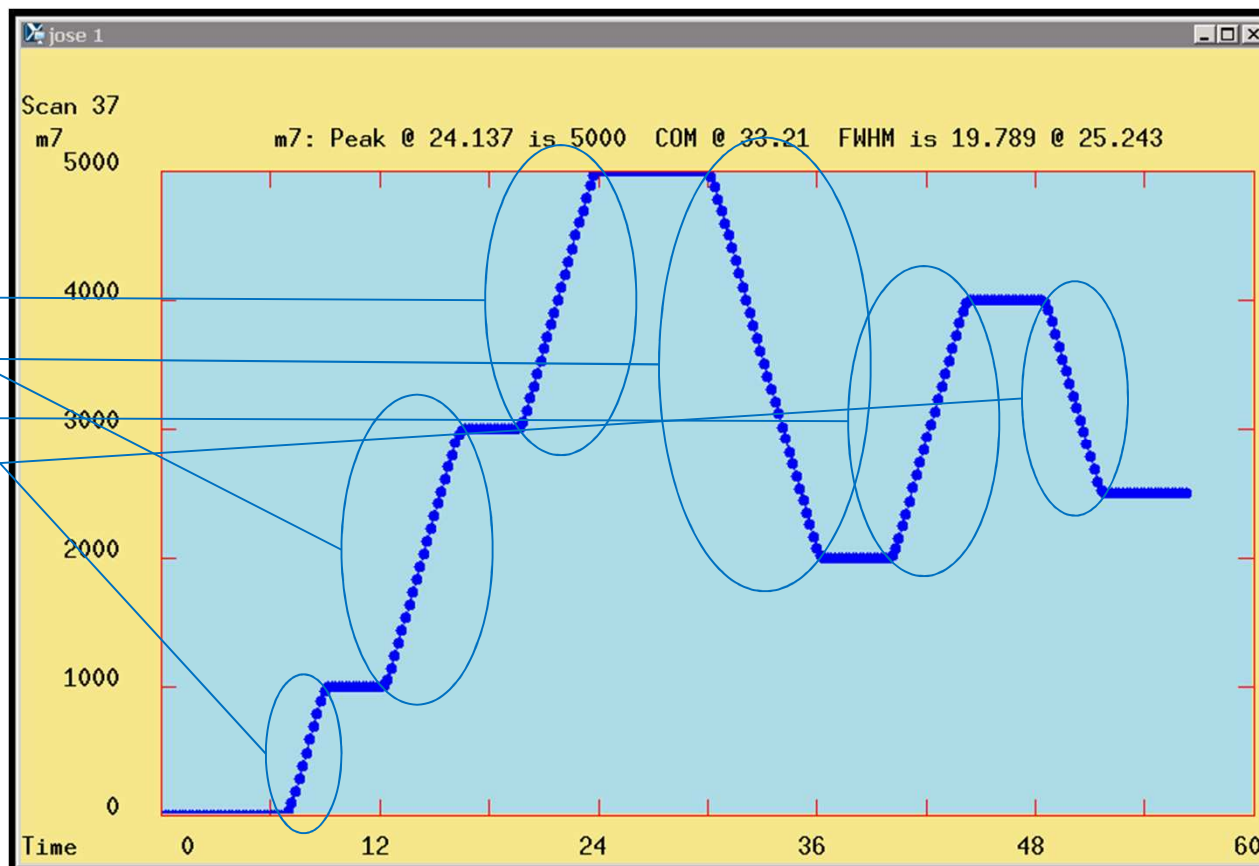
7:MOVE1 3

7:MOVE1 5

7:MOVE1 2

7:MOVE1 4

7:MOVE1 2.5



# TRACKING

## TRACK command

The driver follows an external position signal (INPOS, ENCIN, ABSENC, SYNC)

Trajectory generated internally

Acceleration ramp and max velocity internally defined

Example:

```
23:TRACK ENCIN
```

```
23:STOP // to stop tracking the encoder
```

## Tracking an encoder following a predefined list of positions

Like track, but the position (in steps) of the external position source is used as index in the list

Target position continuously updated

Rotating shutters can be implemented with this function:

```
4:LISTDAT 0 1000 2 // two positions: 0-> closed, 1000 -> open  
4:1 TRACK INPOS
```

Jose Maria Clement. 01/06/2015

# EXTERNALLY TRIGGERED MOTIONS

## External indexer

The driver acts as a power driver, following an externally generated position signal.

No internal limitation of speed or acceleration.

## Motion triggered on external signals

A single movement command executed at an external hardware signal, or after a certain time

AT and WAIT commands

Examples:

3:AT RISE ENCAUX; 3:RMOVE 1000

5:WAIT 0.4; 5:MOVE 2000

Jose Maria Clement. 01/06/2015

# SPECIAL SEQUENCES

## Triggered sequences

At every defined event in an external signal, the axis moves to the next position in the list

```
3:AT RISE <ext_signal>; 3:LTRACK TRIGGER
```

New events are not taken into account during movements!

## Repeated sequences

Similar to triggered sequences, but as the axis reaches a position in the list, it stops and triggers the next sequence as the axis reaches a

```
7:LISTDAT 0 10000 11
```

```
7:LTRACK TRIGGER
```

# ELECTRONIC CAM



**A useful way to synchronise detectors with axes positions without the need of any other hardware.**

**A synchronisation output pulse in each driver**

At given position intervals: ECAMDAT <first\_pos> <last\_pos> <n\_of\_points>

At positions predefined in a list loaded in the driver: \*ECAMDAT <bindatalist>

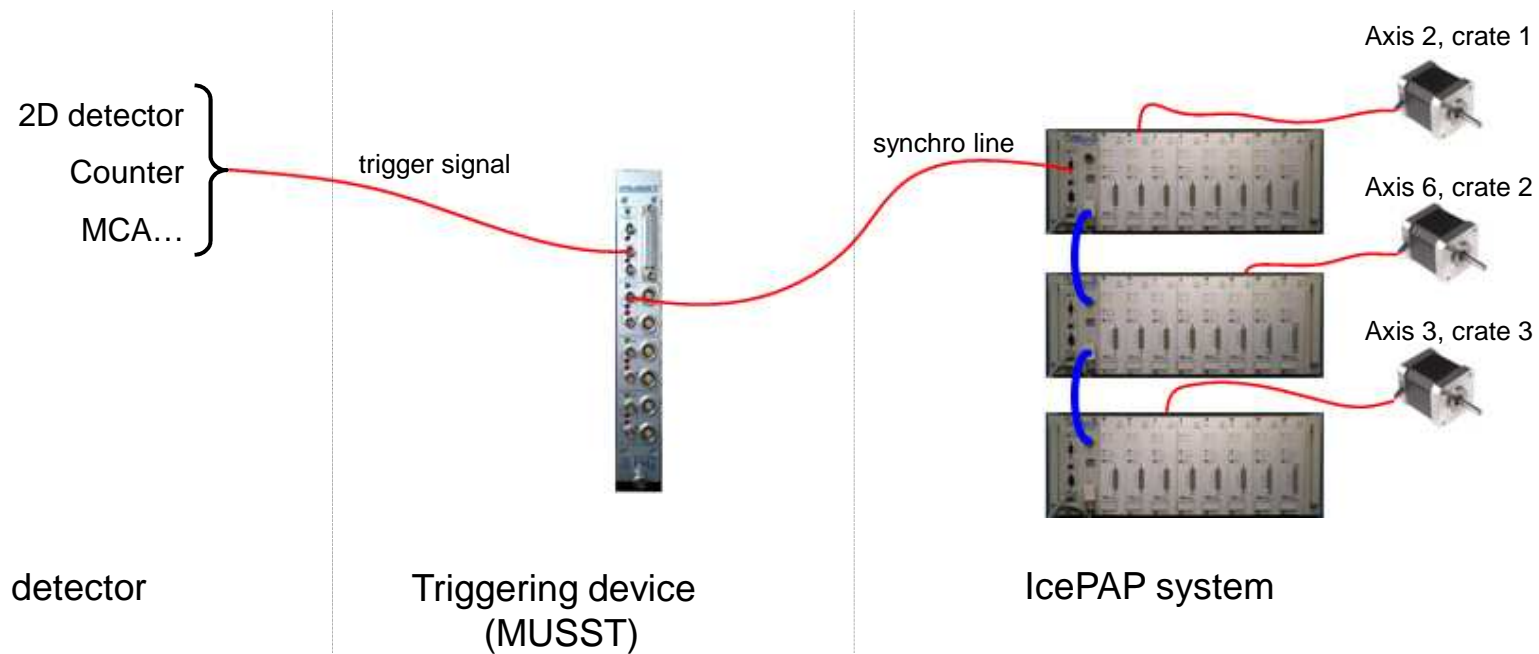
**Possible position sources:**

internal positions

Jose Maria Clement. 01/06/2015



# POSITION SIGNAL MULTIPLEXER



# POSITION SIGNAL MULTIPLEXER IMPLEMENTATION

## Two independent kinds of signals

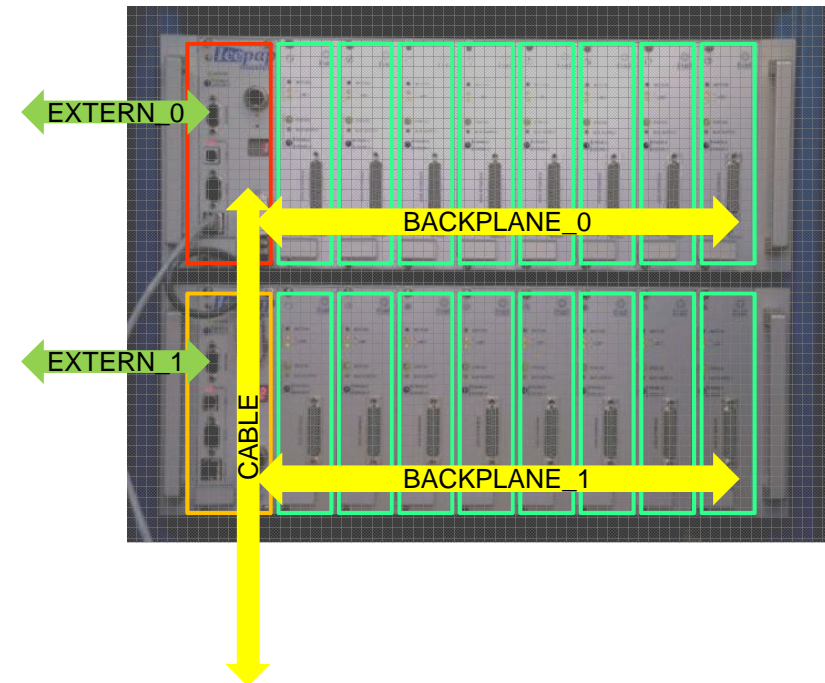
- Pos
- Aux

## Five kinds of PMUX resources

- DRIVER (B)
- CONTROLLER (B)
- CABLE (C)
- BACKPLANE(R)
- EXTERN connector (E)

PMUX system command:

PMUX <signal\_type> <src> <dest>



# POSITION SIGNAL MULTIPLEXER IMPLEMENTATION

## Examples:

Send position signal from extern 0 to driver 12:

PMUX POS E0 B12

12:TRACK SYNC //more on this later...

Send aux signal from driver 3 to extern 0

PMUX AUX B3 E0

3:SYNCAUX ECAM

Get PMUX configuration:

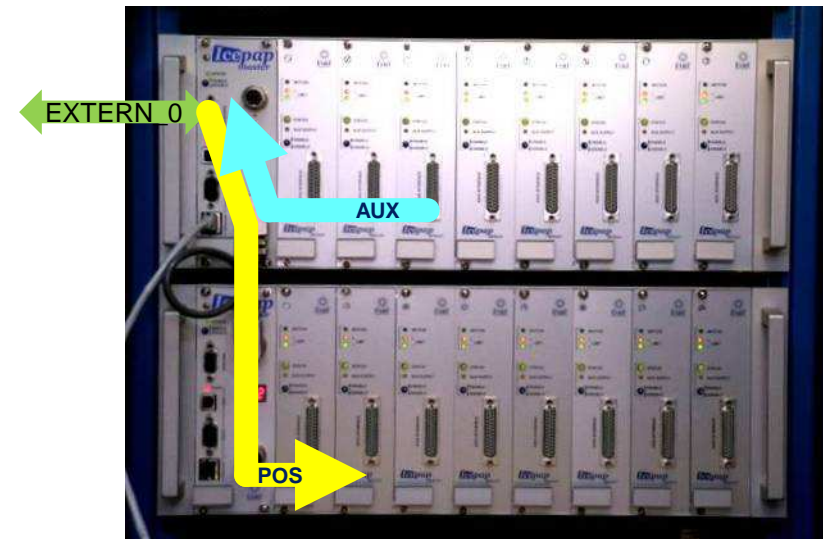
?PMUX

\$

PMUX AUX B3 E0

PMUX POS E0 R1

\$

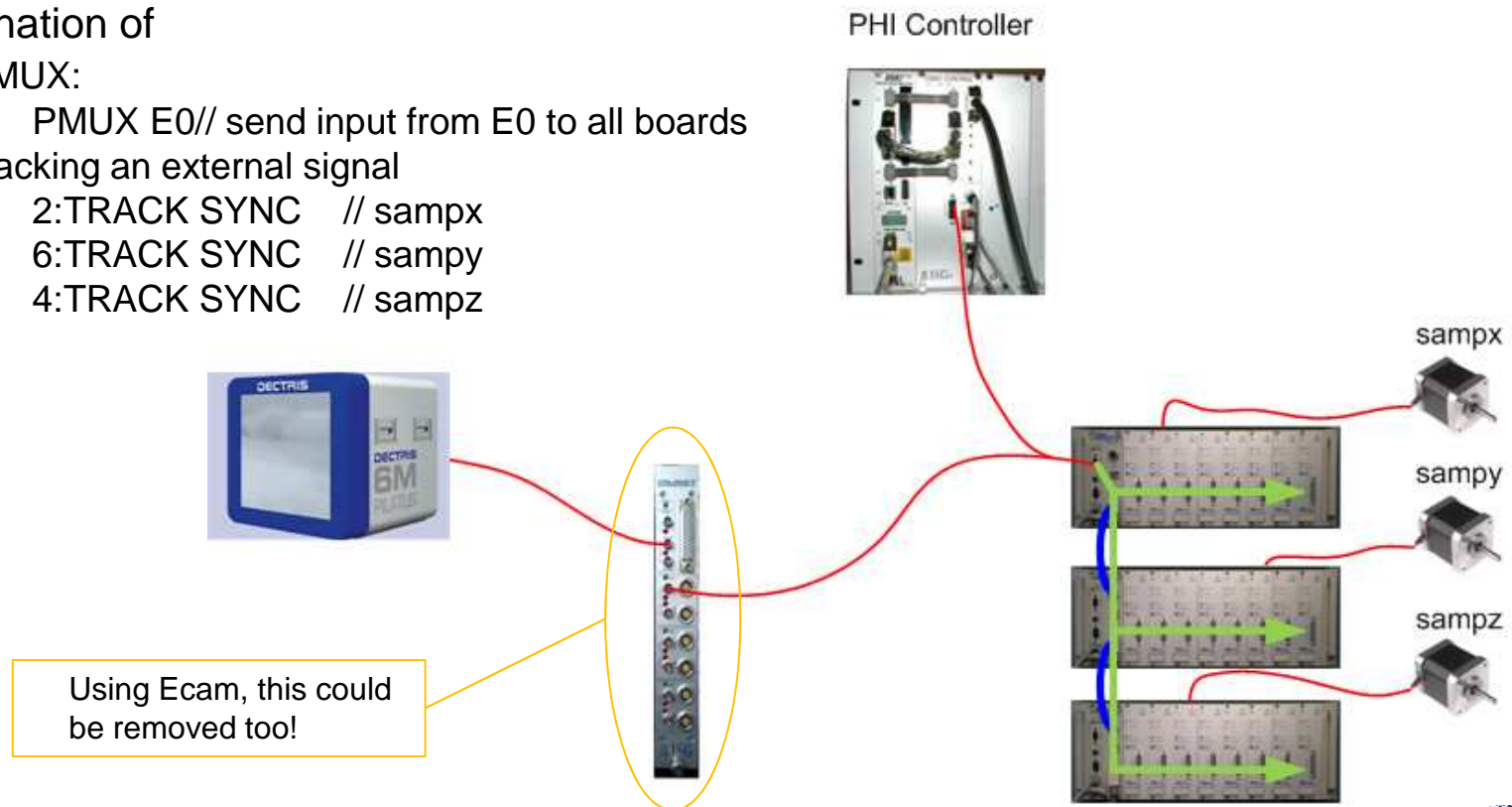


# EXAMPLE OF APPLICATION: HELICAL SCAN IN MX BEAMLINE ID23

- The sample crystal is rotated (PHI) and simultaneously translated in 3 perpendicular directions (sampx, sampy, sampz)

A combination of

- PMUX:  
PMUX E0// send input from E0 to all boards
- Tracking an external signal  
2:TRACK SYNC // sampx  
6:TRACK SYNC // sampy  
4:TRACK SYNC // sampz



# EXTERNAL MEASURE REGULATION

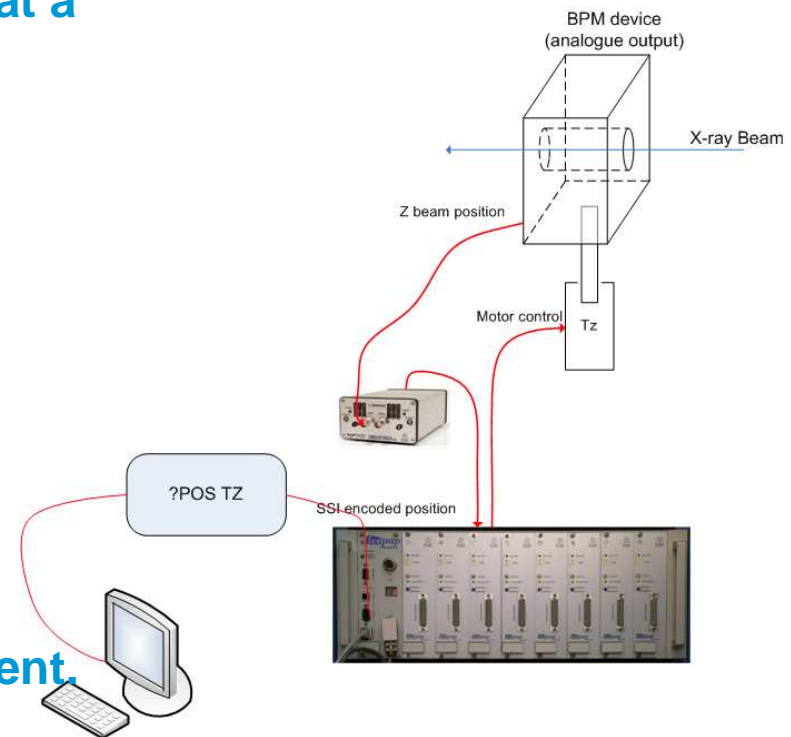
The IcePAP axis position changes automatically in order to keep a certain measured quantity at a specified value

## Measure source:

- encoder input (incremental / absolute)
- software value updated regularly from the control PC

Only requirement is a monotonous relation between measure and axis position

The axis position can be queried at any moment.



## Regulation settings:

- Gain, time constant, software limits, deadband

Jose-Manuel Clement, 01/06/2015

# PARAMETRIC TRAJECTORIES

## Parametric Tables

A parametric table can be loaded on each driver.

The table describes a curve:

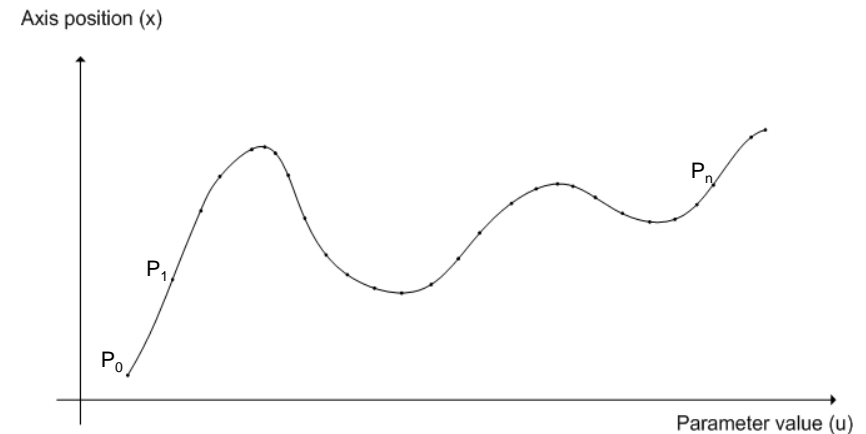
$$x=f(u)$$

The table is composed of points (P), each defined by:

- parameter, position  $P_n \rightarrow (u_n, x_n)$
- parameter, position, slope  $P_n \rightarrow (u_n, x_n, dx_n/du_n)$

Positions of the curve between table points will be interpolated (linear, or cubic splines).

Tables can be circular (for periodic movements).





# PARAMETRIC TRAJECTORIES

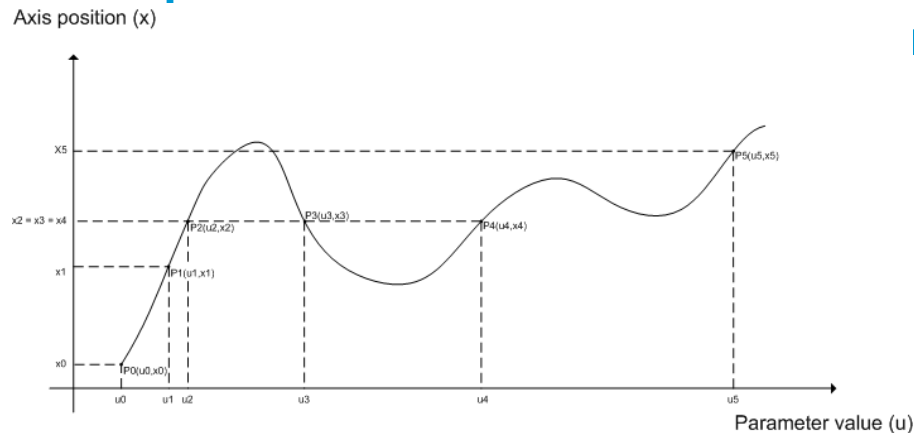
## Parametric Trajectories

### PMOVE u

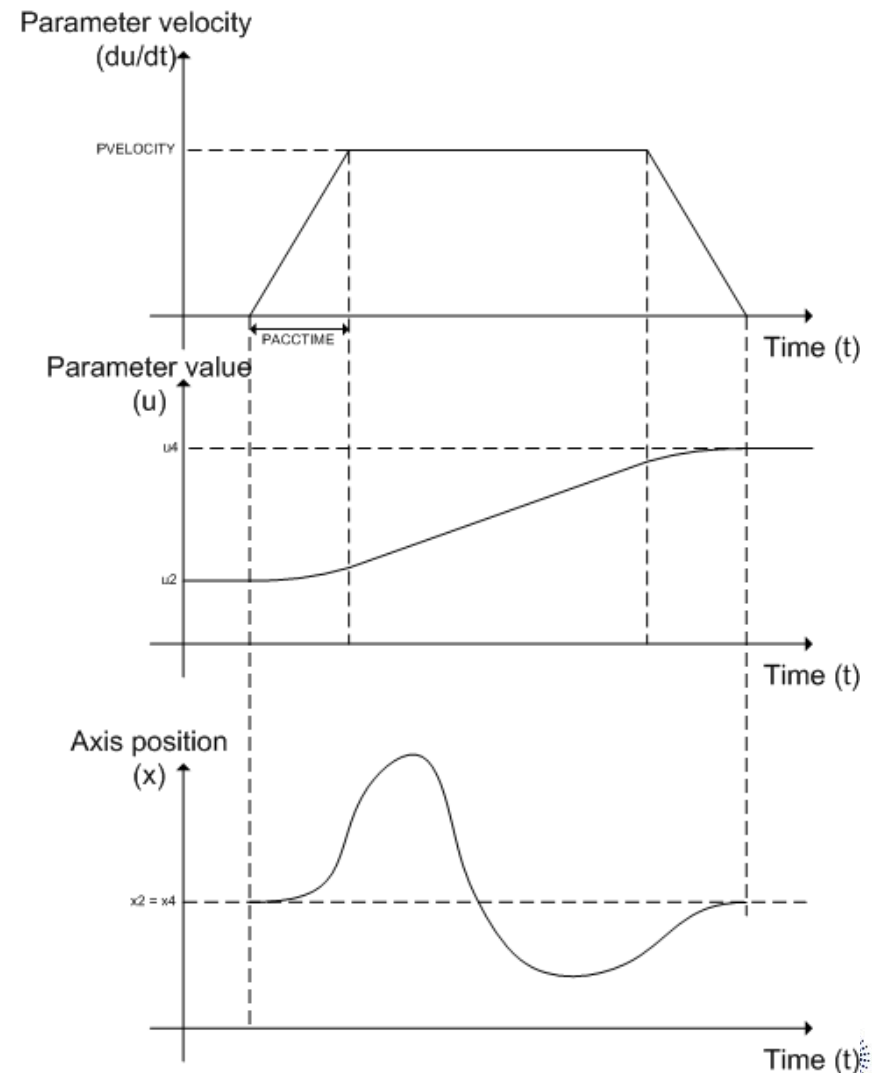
Movement following the parametric curve, to parameter value u.

The parameter time evolution will be

nd



Jose Maria Clement. 01/06/2015



# PARAMETRIC TRAJECTORIES

**Multiaxes parametric curves (curves in n-dimension space) are defined by the relations:**

$$x_1=f_1(u), x_2=f_2(u), \dots, x_n=f_n(u)$$

**The parametric movement commands will have multiaxes versions.**

**A table describing each curve must be loaded in each axis.**

**A multiaxes MOVEP command must then be sent once to send (normal movement) each axis to the position (x) corresponding to a parameter value (u) in the curve:**

**MOVEP u <axis<sub>1</sub>> <axis<sub>2</sub>> ... <axis<sub>n</sub>>**

**Parameters PARVEL and PARACCT must be defined**

**After this, movements along the curve are allowed, and executed with the multiaxes PMOVE:**

**PMOVE u <axis<sub>1</sub>> <axis<sub>2</sub>> ... <axis<sub>n</sub>>**

# PARAMETRIC TRAJECTORIES: AN EXAMPLE

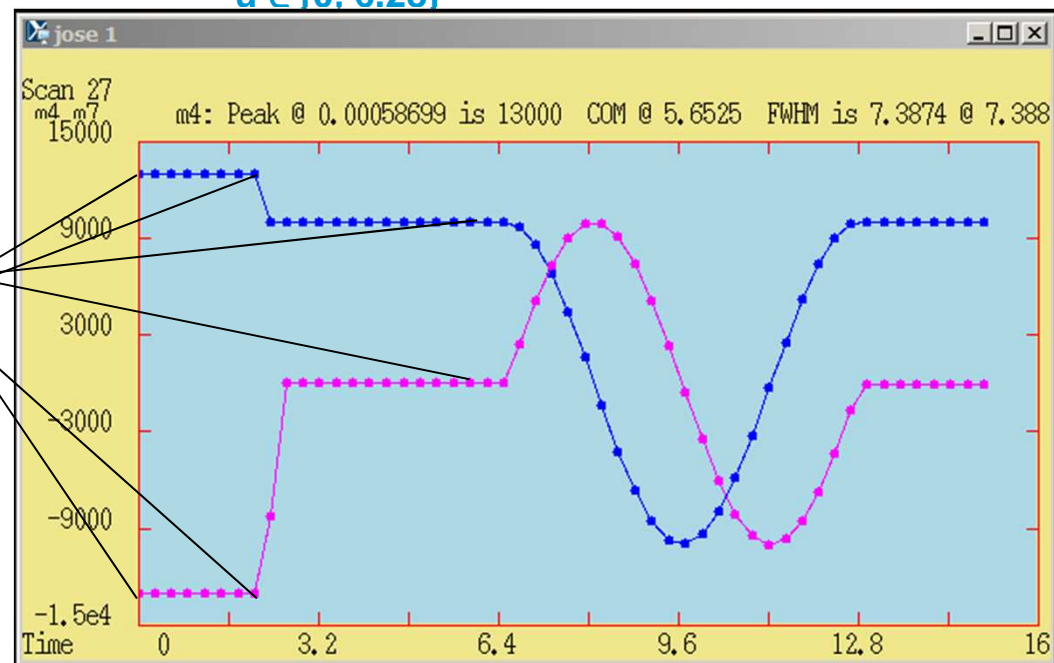
With a simple python script two tables with 1000 values each were created and loaded:

$$x_1 = 10000 \sin(u)$$

$$x_2 = 10000 \cos(u)$$

$$u \in [0, 6.28]$$

Then, both axes  
Now, both axes can  
First, both axes  
be moved along the  
are out of the  
parametric curve, for  
trajectory  
example, for  $u = 6.28$   
 $x_1 = 13000$   
 $x_2 = -13000$   
 $x_2 = 10000$   
MOVEP 0 4 7



# ICEPAP FIRMWARE: COMING FEATURES

## Data recording (oscilloscope mode)

Recording of positions, time, internal variables

Configurable Internal and external triggers

Different trigger/recording modes

Available memory: 1MByte (to be shared with Ecamdat, Listdat, Parametric table...)

## Additional motor types

DC brushed motors

3-Phase stepper

3-phase synchronous and brushless motors

Only digital encoders as shaft position sensor, no support for analog sensors (resolvers, tachometers, hall effect sensors...)

Jose Maria Clement. 01/06/2015

Grand European Synchrotron

