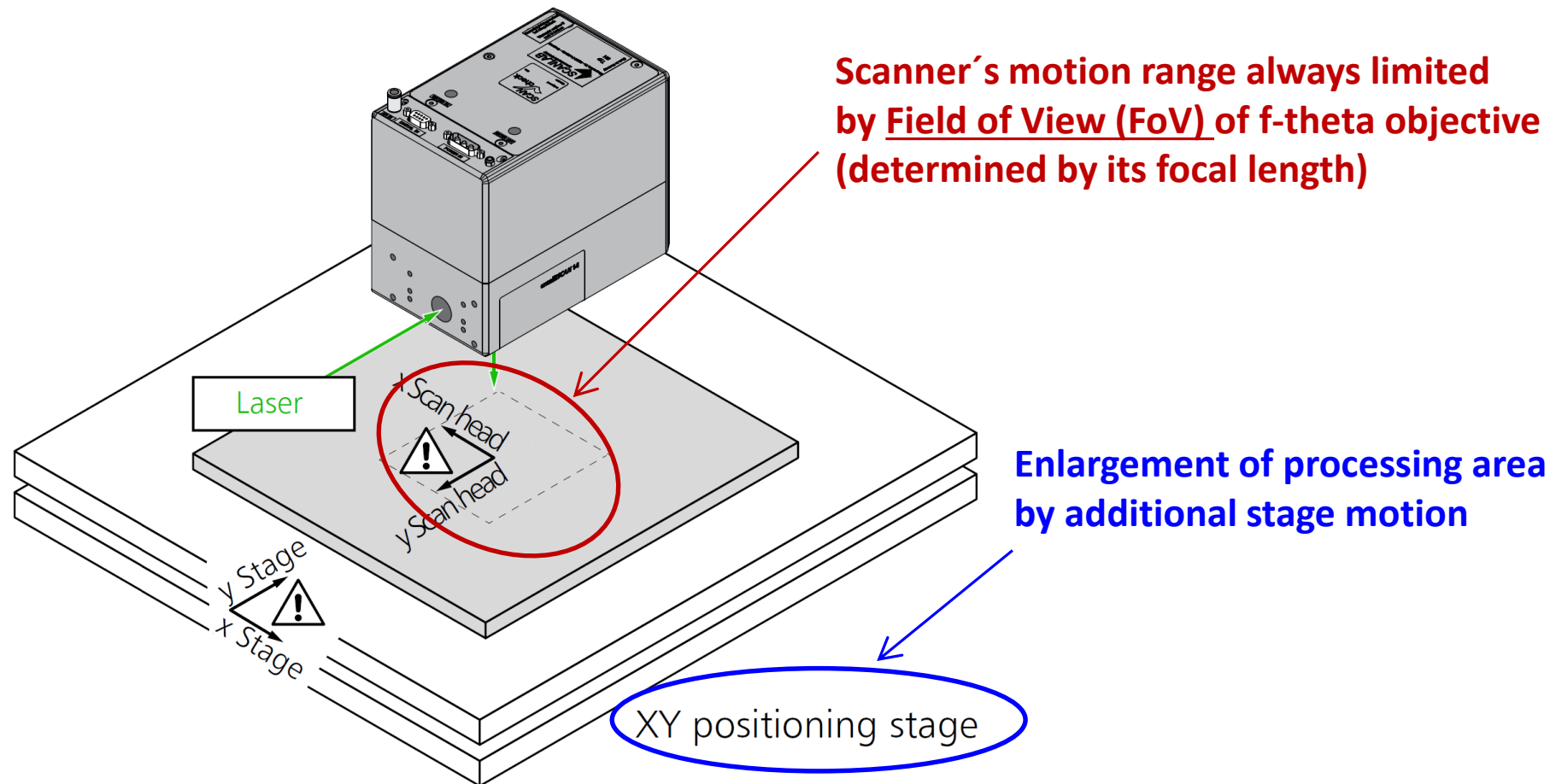# Introduction to MoF / PoF mode of RTC6
with excelli*SCAN* (+ emulated enc. signal)

MSL, Aug. 2022

Large-area laser processing
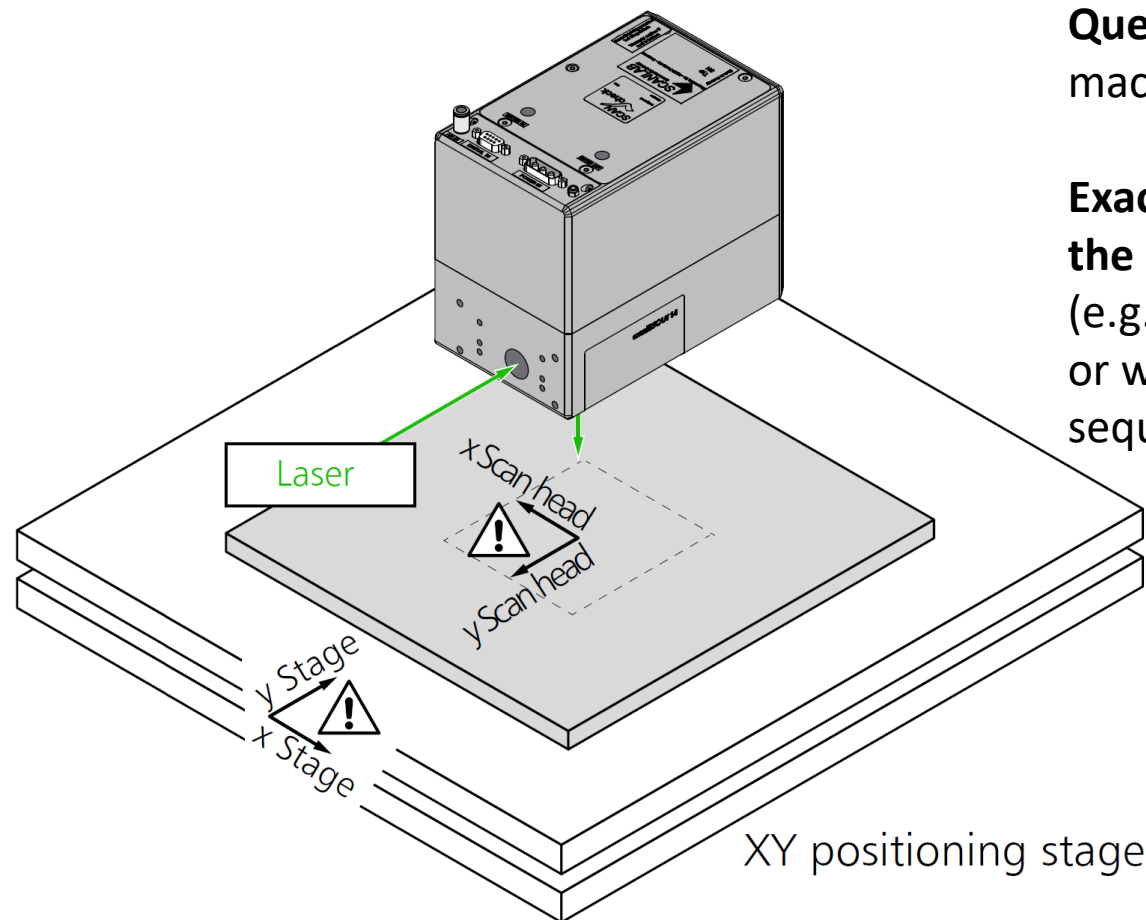## with scanner + stage

Scanner´s motion range always limited by <u>Field of View (FoV)</u> of f-theta objective (determined by its focal length)

Laser

x Scan head
y Scan head

y Stage
x Stage

Enlargement of processing area by additional stage motion

XY positioning stage

Large-area laser processing
with scanner + stage

Laser

x Scan head

y Scan head

y Stage

x Stage

XY positioning stage

Question to be answered before machine concept development**:**

**Exactly how shall the scanner axes and the stage axes operated?**
(e.g. whether with synchonized control or without, which motions in which sequential order)

Large-area laser processing
with scanner + stage

Laser

x Scan head

y Scan head

y Stage

x Stage

XY positioning stage

Various appoaches:

a) Tiling & Stitching

b) MoF (Marking on the Fly)
   a.k.a PoF (Processing on the Fly)

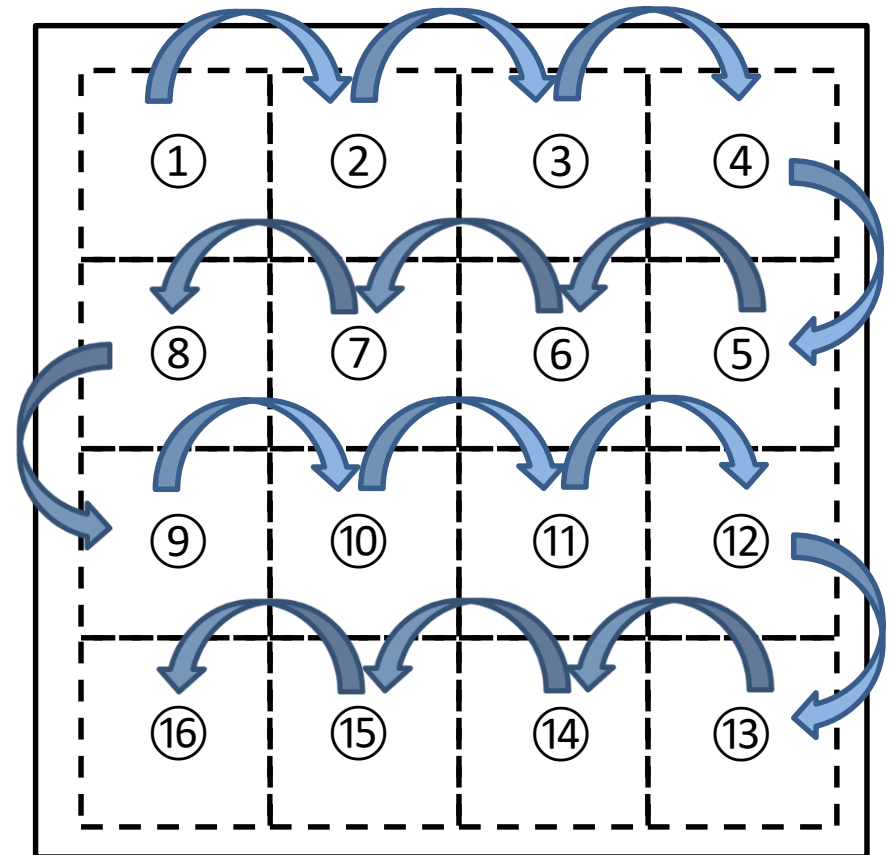c) Fully Synchronized Control
   by sync*AXIS* SW in XL *SCAN*
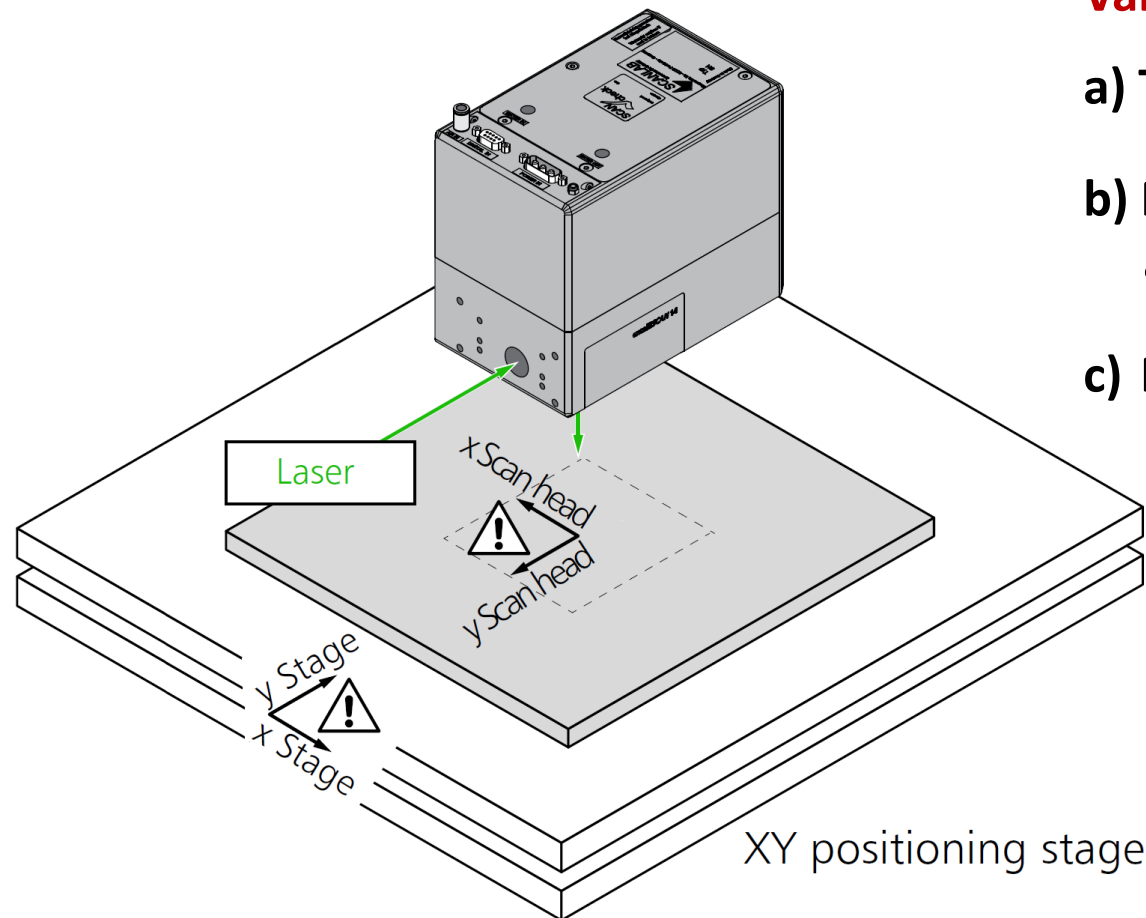
Large-area laser processing
with scanner + stage

Various appoaches:

a) Tiling & Stitching

- Processing partitioned into
  smaller tile units (coverable by FoV)

- Step-by-Step motion by stage
  from one tile unit to the next
  => centering FoV to each tile unit

- Stage remaining stationary
  while scanner being operated for
  laser processing in each tile unit

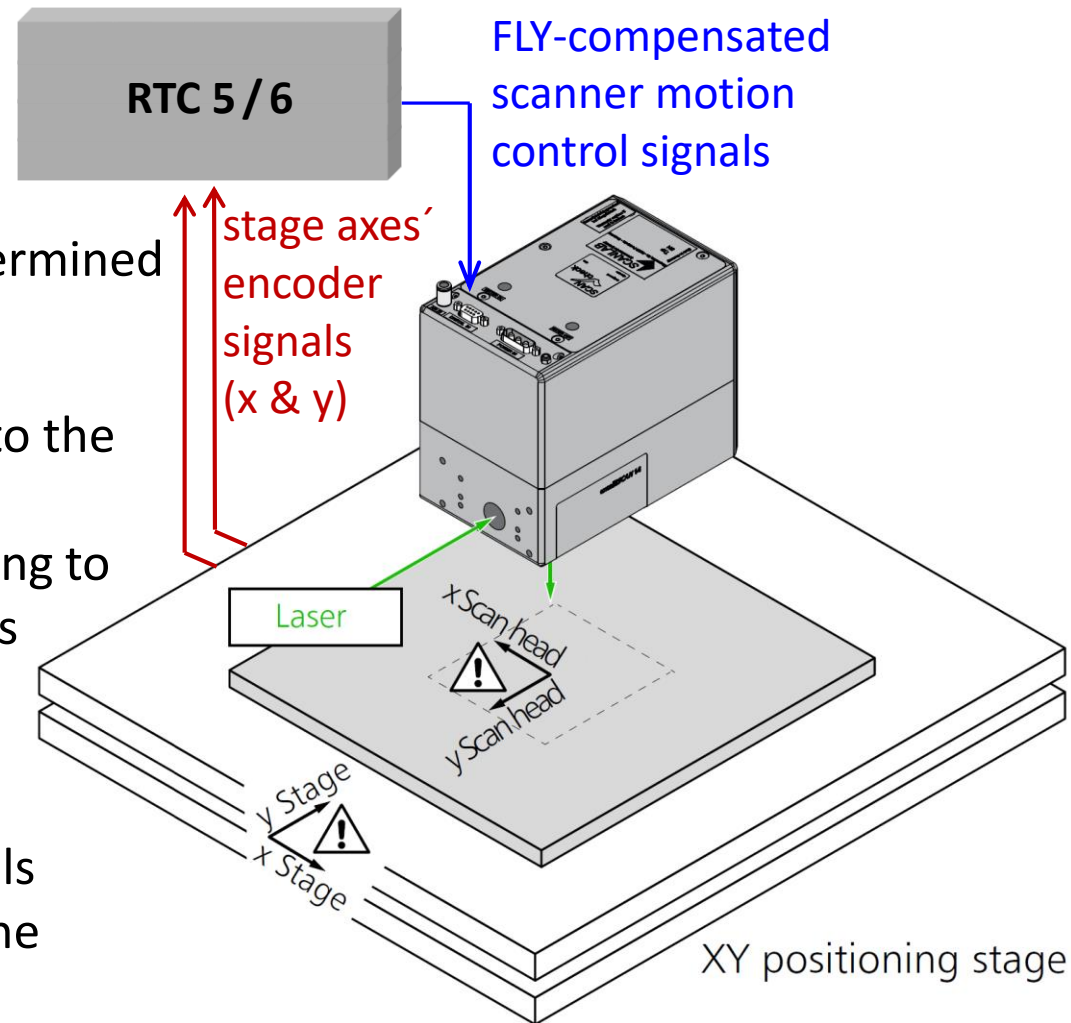Example of tiling-and-stitching approach

Large-area laser processing
with scanner + stage

Various appoaches:

b) MoF / PoF

- Stage's motion trajectory pre-determined and controlled by user

- Stage axes' encoder signals fed into the RTC board
  => providing the data corresponding to the stage's position coordinates

- Scanner motion automatically corrected by the RTC's calculation based on the fed-in encoder signals
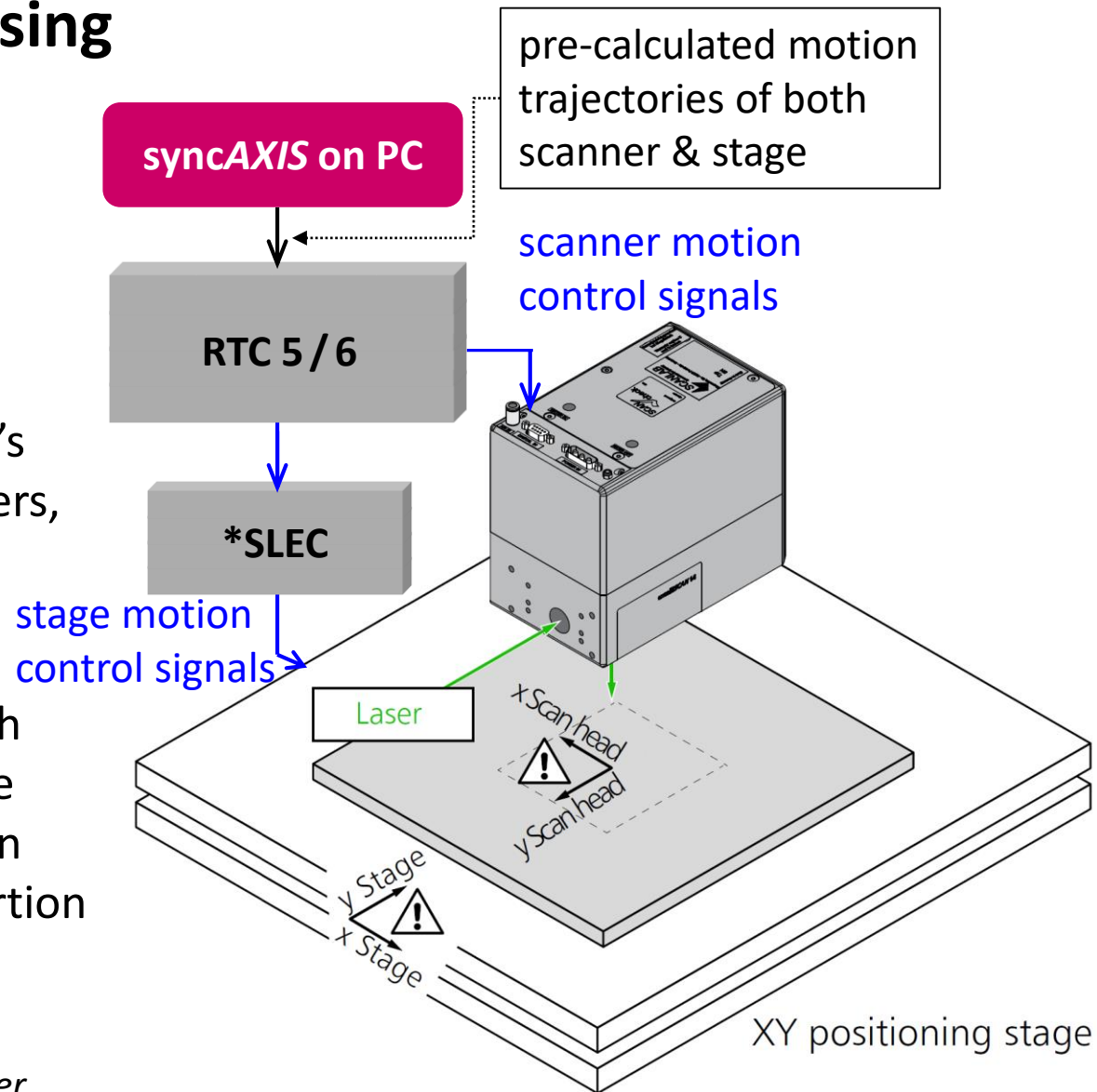 => scanner passively reacting to the stage motion

RTC 5 / 6

FLY-compensated scanner motion control signals

stage axes´ encoder signals (x & y)

Laser

x Scan head

y Scan head

y Stage

x Stage

XY positioning stage

Large-area laser processing
with scanner + stage

Various appoaches:

**c) Fully Synchronized Control
   by sync*AXIS* SW in XL *SCAN***

- User input only for laser spot's
  motion path, speed parameters,
  and dynamic constraints

- The sync*AXIS* SW takes care
  of trajectory planning for both
  scanner & stage as well as the
 decomposition of spot motion
  into scanner's and stage's portion

* : *SLEC = SL2-100 to EtherCAT Converter*

pre-calculated motion
trajectories of both
scanner & stage

sync*AXIS* on PC

scanner motion
control signals

RTC 5 / 6

SLEC

stage motion
control signals

Laser

x Scan head
y Scan head

y Stage
x Stage

XY positioning stage

Large-area laser processing
with scanner + stage

Laser

x Scan head
y Scan head

y Stage
x Stage

XY positioning stage

Various appoaches:

a) **Tiling & Stitching**

b) **MoF (Marking on the Fly)**
   a.k.a PoF (Processing on the Fly)

c) **Fully Synchronized Control**
   by sync*AXIS* SW in XL *SCAN*

Large-area laser processing
with scanner + stage

Laser

x Scan head
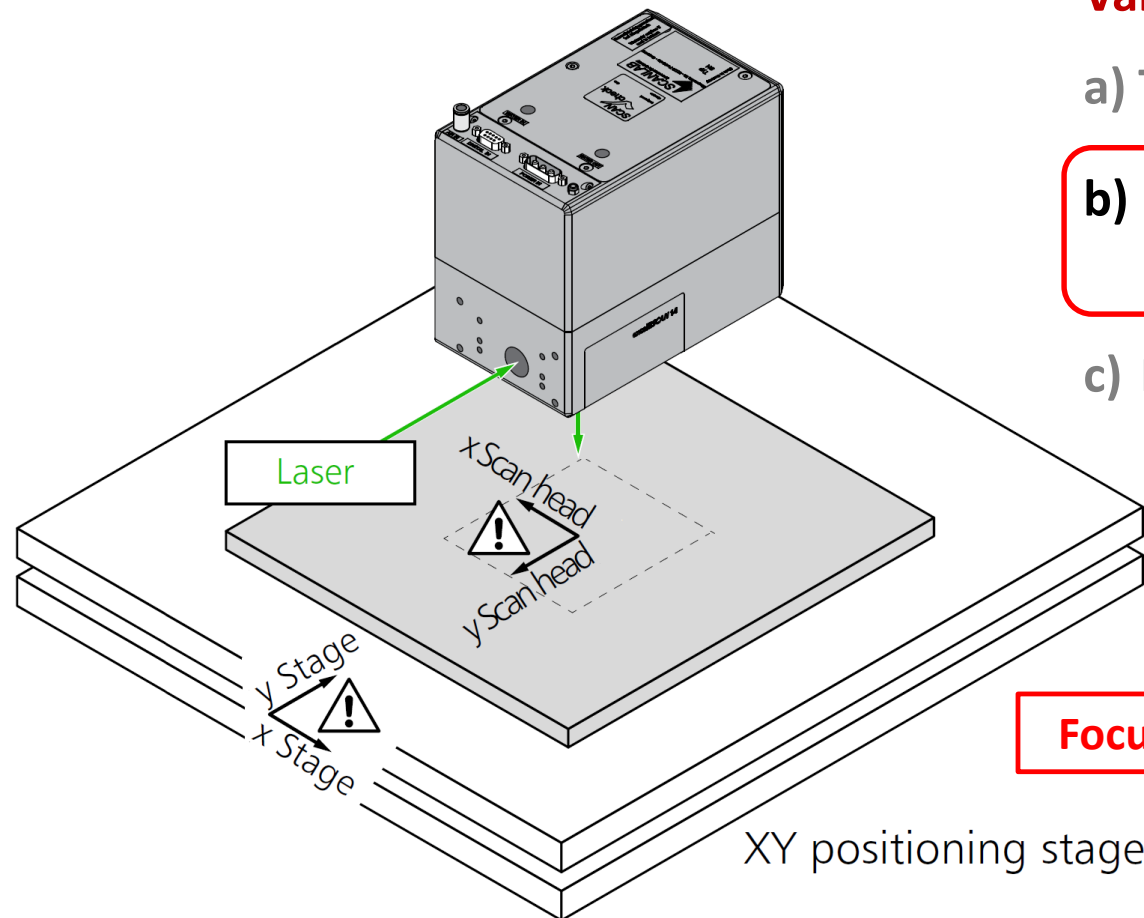y Scan head

y Stage
x Stage

XY positioning stage
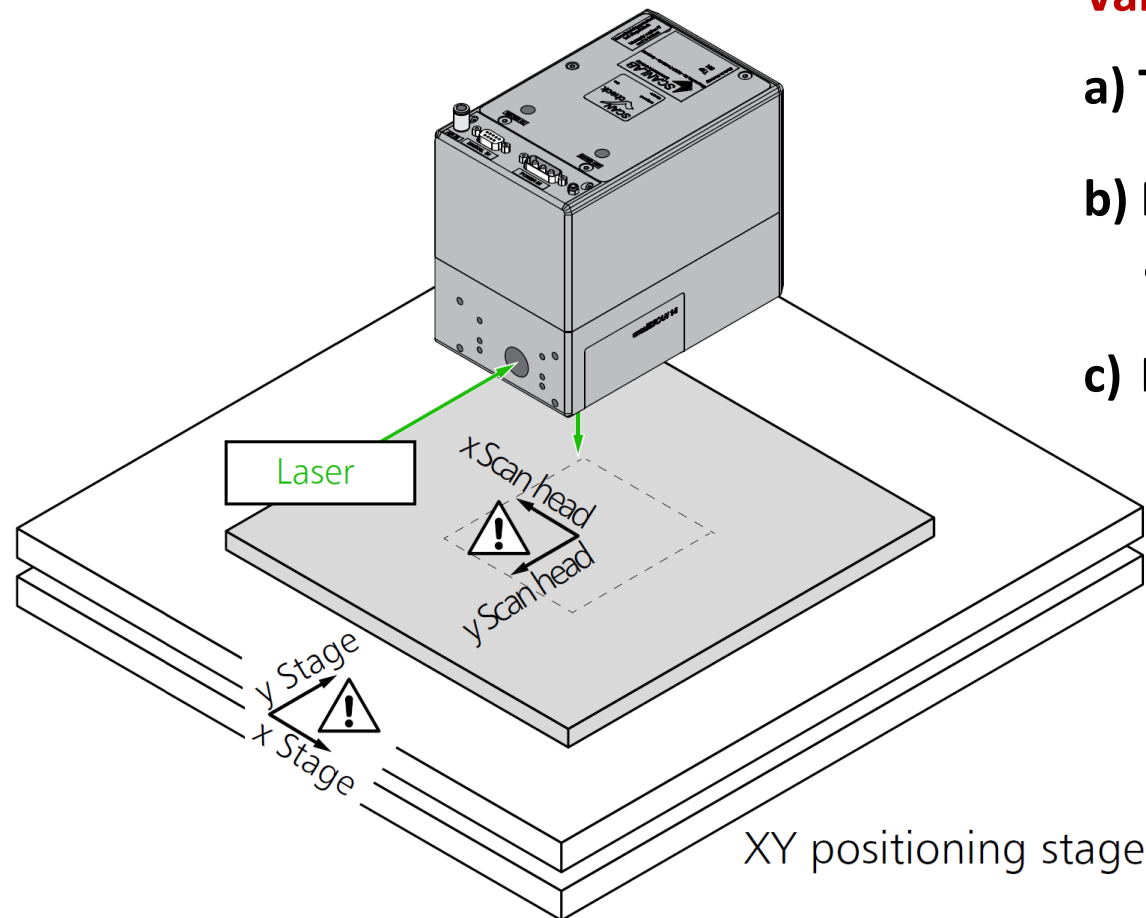
Various appoaches:

a) Tiling & Stitching

b) MoF (Marking on the Fly)
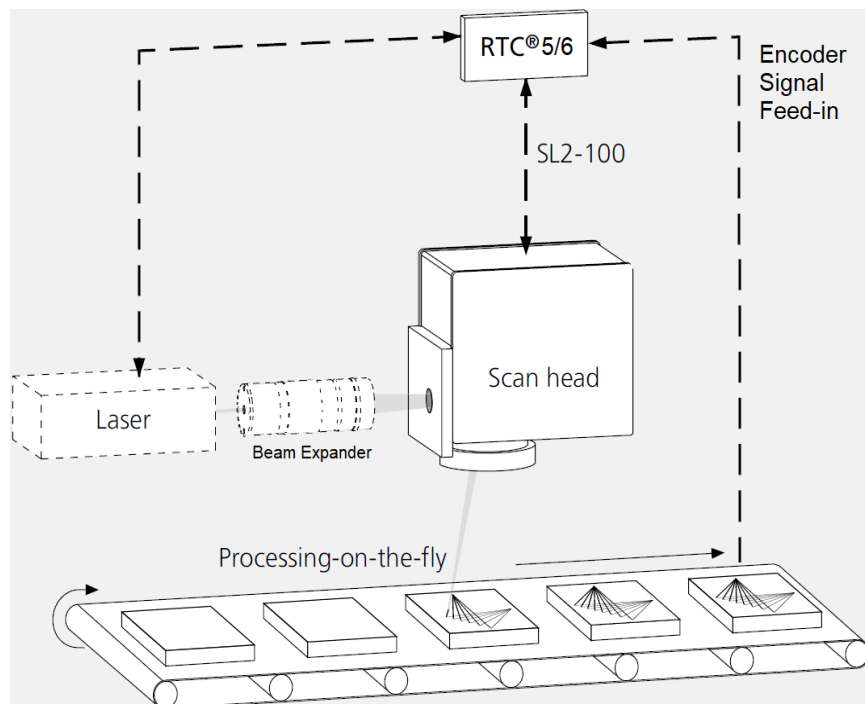   a.k.a PoF (Processing on the Fly)

c) Fully Synchronized Control
   by sync*AXIS* SW in XL *SCAN*
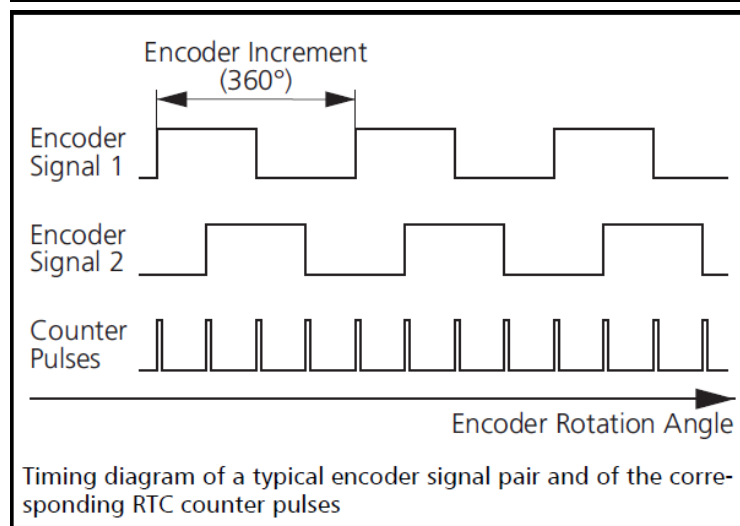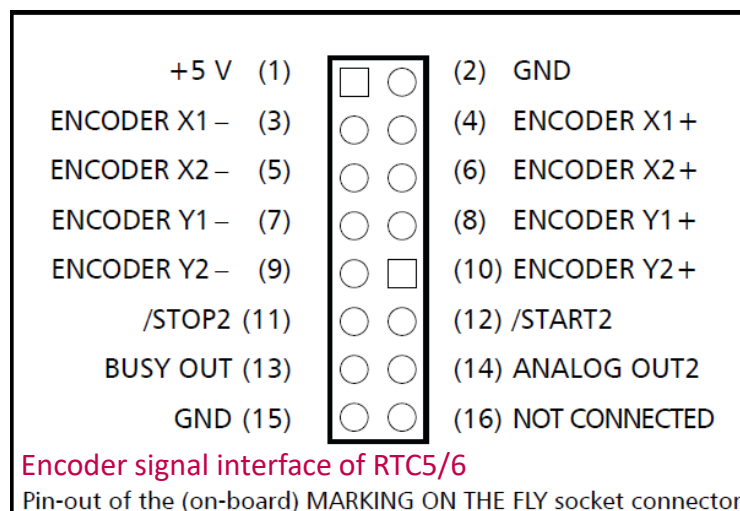
Focus of today´s presentation

MoF (Marking on the Fly) / PoF (Processing on the Fly)
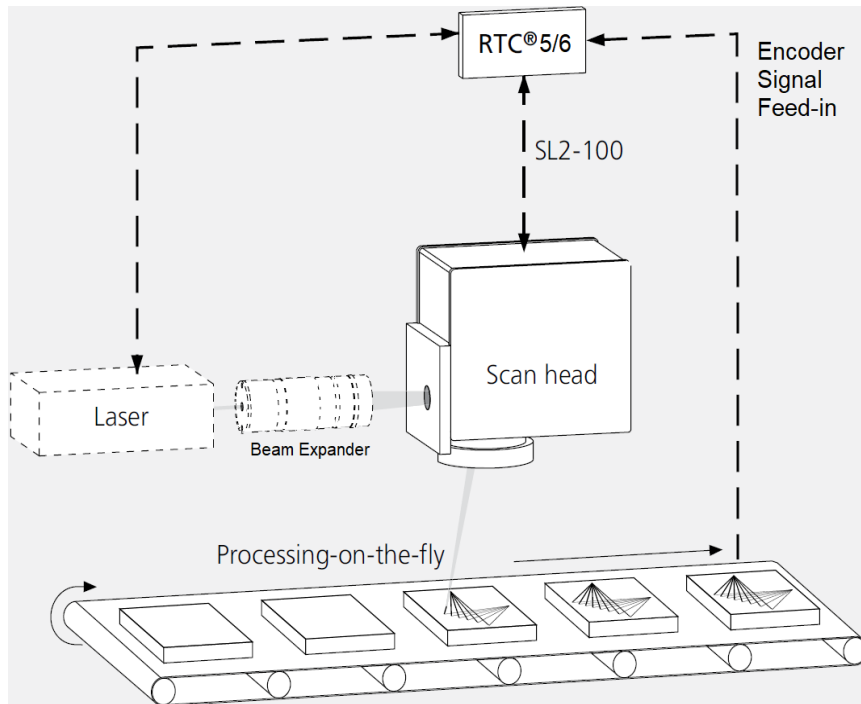
Original purpose: 1D FLY with const. speed

- RS422 (HIGH ≥ 2.0 V; LOW ≤ 0.8 V)

- Max. allowed encoder frequency: 4 MHz for RTC5/6 (i.e. max. 160 encoder pulses within 10 µs)

- Two encoder signals phase-shifted by 90° for each stage axis (X1 & X2 and Y1 & Y2)

+5 V	(1)	(2)	GND
ENCODER X1 –	(3)	(4)	ENCODER X1+
ENCODER X2 –	(5)	(6)	ENCODER X2+
ENCODER Y1 –	(7)	(8)	ENCODER Y1+
ENCODER Y2 –	(9)	(10)	ENCODER Y2+
/STOP2	(11)	(12)	/START2
BUSY OUT	(13)	(14)	ANALOG OUT2
GND	(15)	(16)	NOT CONNECTED

Encoder signal interface of RTC5/6
Pin-out of the (on-board) MARKING ON THE FLY socket connector

Timing diagram of a typical encoder signal pair and of the corresponding RTC counter pulses

MoF (Marking on the Fly) / PoF (Processing on the Fly)
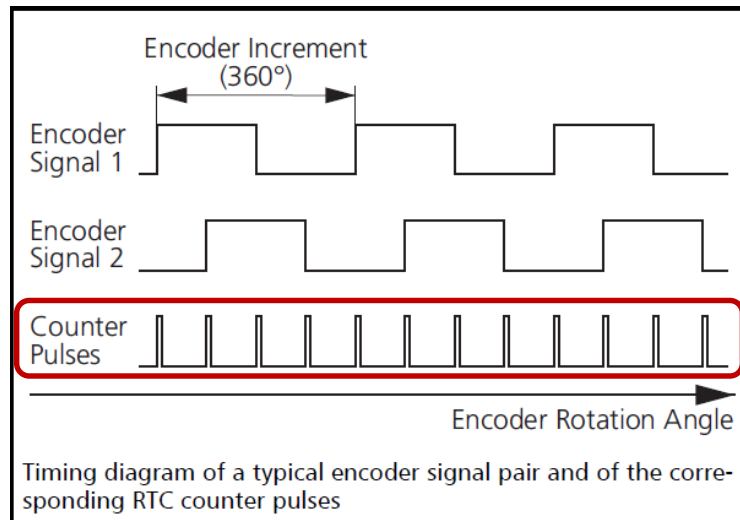
Original purpose: 1D FLY with const. speed

- Each rising or falling edge => 1 encoder pulse count
- Accumulated encoder pulse counts represent the stage's position coordinates.
- Motion direction indicated by phase shift between Enc. 1 & Enc. 2 => pos. or neg. pulse counts

Encoder signal interface of RTC5/6
Pin-out of the (on-board) MARKING ON THE FLY socket connector

Timing diagram of a typical encoder signal pair and of the corresponding RTC counter pulses

MoF (Marking on the Fly) / PoF (Processing on the Fly)

Original purpose: 1D FLY with const. speed

RTC®5/6

Encoder Signal Feed-in

SL2-100

Scan head

Laser

Beam Expander

Processing-on-the-fly

+5 V (1)		(2) GND
ENCODER X1– (3)		(4) ENCODER X1+
ENCODER X2– (5)		(6) ENCODER X2+
ENCODER Y1– (7)		(8) ENCODER Y1+
ENCODER Y2– (9)		(10) ENCODER Y2+
/STOP2 (11)		(12) /START2
BUSY OUT (13)		(14) ANALOG OUT2
GND (15)		(16) NOT CONNECTED

Encoder signal interface of RTC5/6
Pin-out of the (on-board) MARKING ON THE FLY socket connector

Encoder Increment (360°)

Encoder Signal 1

Encoder Signal 2

Counter Pulses

Encoder Rotation Angle

Timing diagram of a typical encoder signal pair and of the corresponding RTC counter pulses
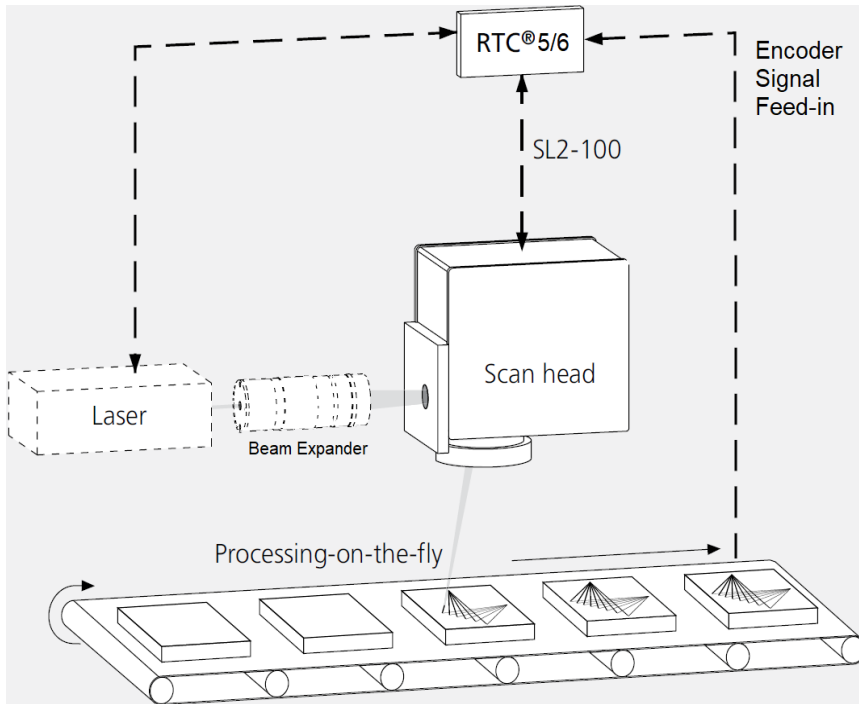
- The frequency of encoder pulses represent the velocity of each stage motor axis.

- However, no present value of instantaneous velocity available, only the values lying in the past

- Stage acc. / dec. => lagging scanner motion => **pos. err.**
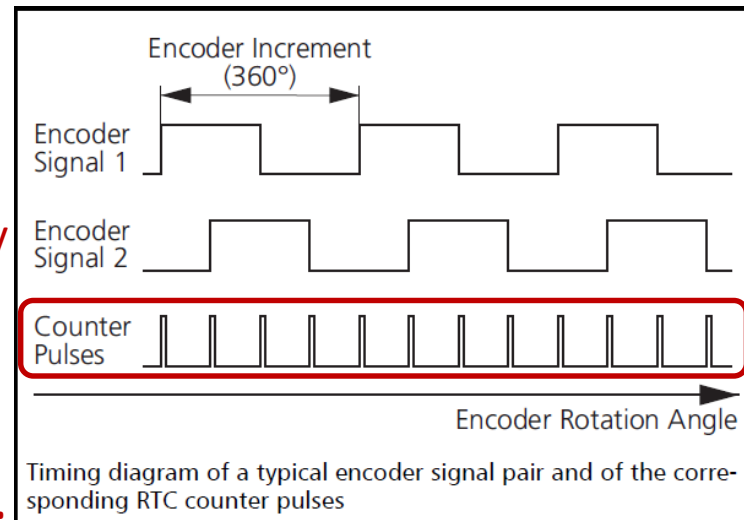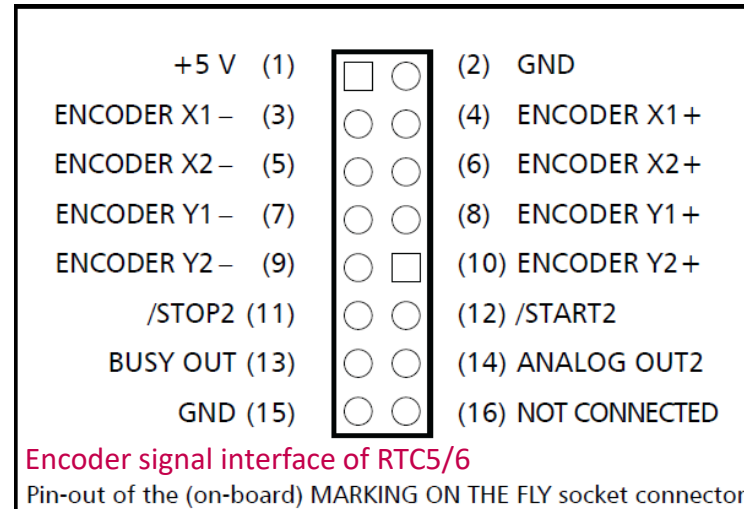
MoF (Marking on the Fly) / PoF (Processing on the Fly)

Difficulty in motion sync. for accelerated / decelerated stage motion

Case 1.: scanner with **conventional** control (*SCAN*cube, hurry*SCAN*, inteill*SCAN* etc.)
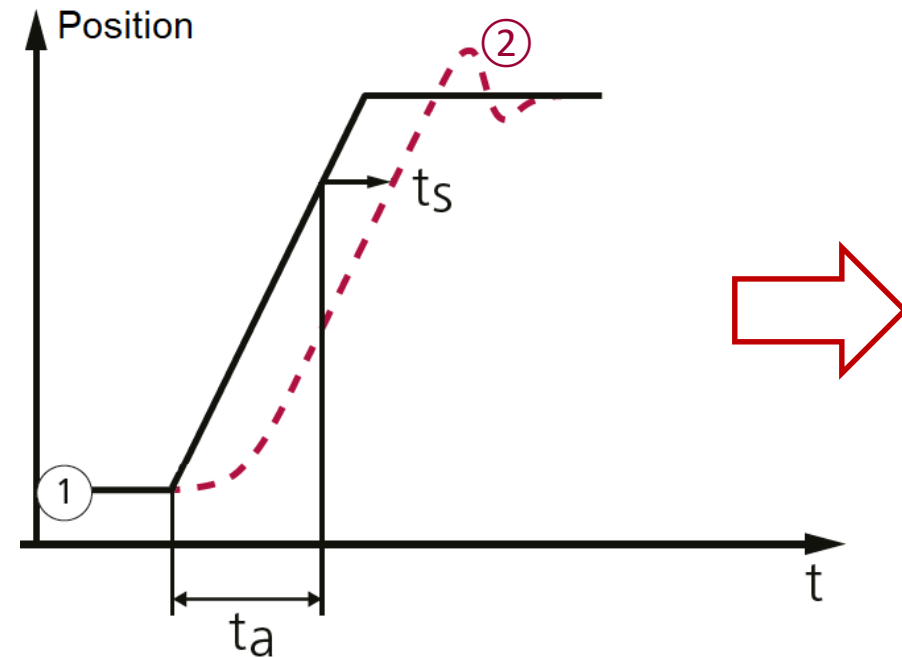
Due to tracking error (typ. 0.1 – 0.6 μsec. depending on scanner type and tuning), the attempt of scanner to follow accelerated or decelerated stage motion based on encoder counts leads to the scanner motion lagging behind the stage motion causing increased position error.

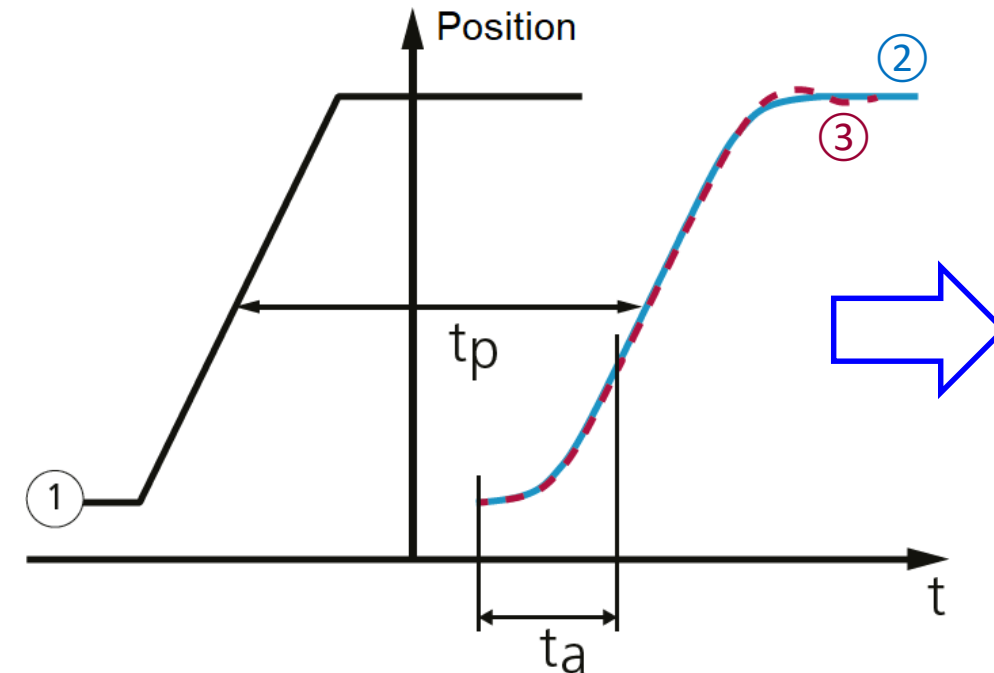t_s = tracking error
t_a = acceleration time
① = set trajectory determined by RTC's control values
② = actual trajectory of scanner motion

MoF (Marking on the Fly) / PoF (Processing on the Fly)

Difficulty in motion sync. for accelerated / decelerated stage motion

Case 2.: scanner with *SCAN*ahead control (i.e. **excelli*SCAN***)

Due to preview time of 1.2 msec., the FLY correction for scanner motion is based on predicted encoder pulse counts calculated by the extrapolation from the encoder pulse frequency / stage speed over the past 1.2 msec.

Any acceleration or deceleration in stage motion will lead to the deviation from these predicted values and, therefore, to increased position error.

t_p = preview time required for calculation in *SCAN*ahead control
t_a = acceleration time
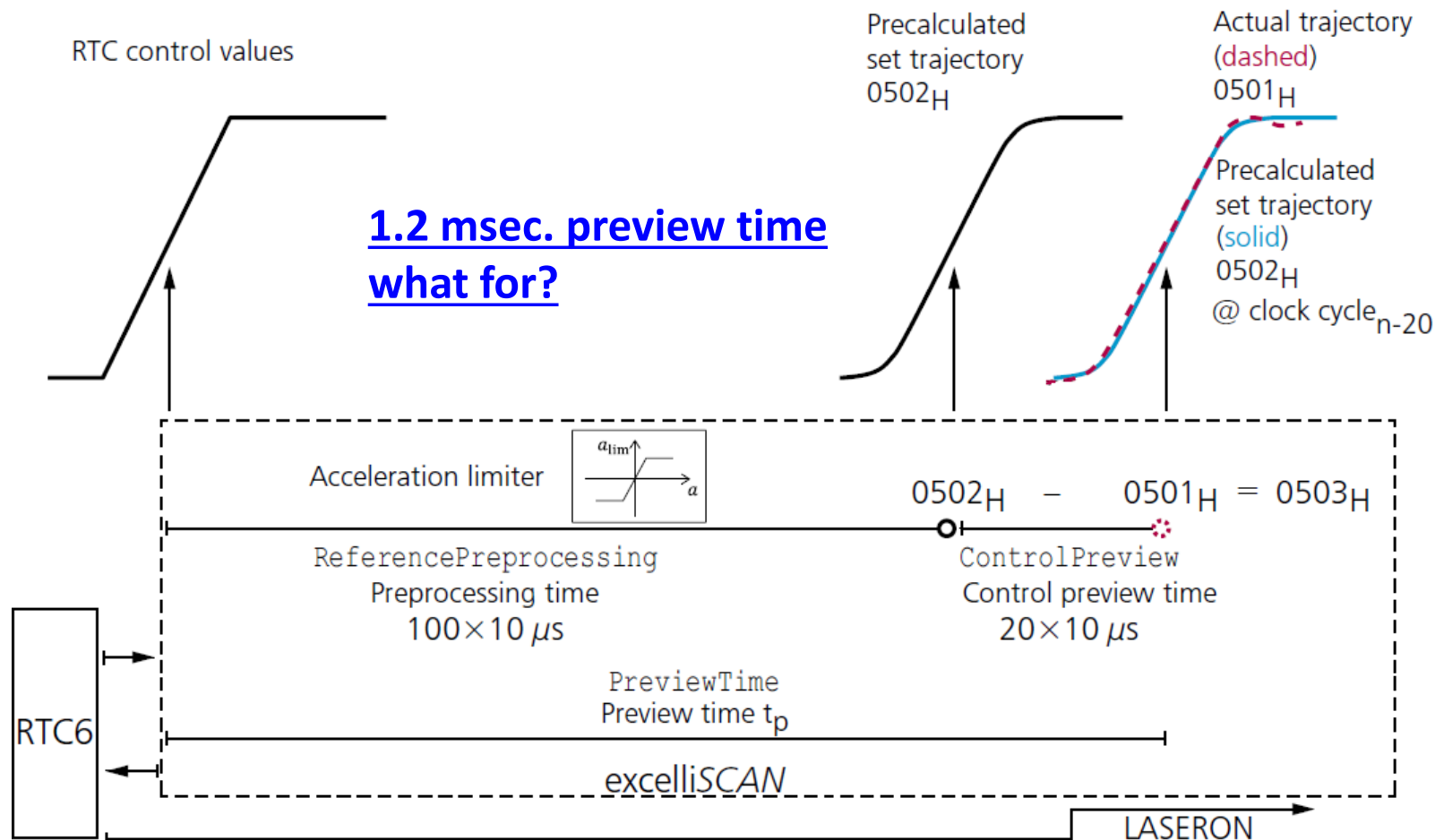① = set trajectory determined by RTC's control values
② = pre-calculated set trajectory from *SCAN*ahead control
③ = actual trajectory from *SCAN*ahead control

MoF (Marking on the Fly) / PoF (Processing on the Fly)

Difficulty in motion sync. for accelerated / decelerated stage motion

Case 2.: scanner with *SCANahead* control (i.e. **excelliSCAN**)

1.2 msec. preview time what for?

RTC control values

Precalculated set trajectory 0502_H

Actual trajectory (dashed) 0501_H

Precalculated set trajectory (solid) 0502_H @ clock cycle$_{n-20}$

Acceleration limiter

$0502_H - 0501_H = 0503_H$

ReferencePreprocessing
Preprocessing time
$100 \times 10 \, \mu s$

ControlPreview
Control preview time
$20 \times 10 \, \mu s$

PreviewTime
Preview time t_p

RTC6

excelliSCAN

LASERON

Solution by emulated / virtual encoder signals

Criteria for solution:

- The encoder signals shall arrive at the RTC6 board ***1.25 msec. before** the stage motion to the corresponding target positions.

- The encoder signals shall represent the stage's target positions with minimized errors.

ACS product named 'LCI' ('Laser Control Interface' in short) generates emulated (a.k.a 'virtual') encoder signals fulfilling these criteria, if the stage motion is also controlled by ACS motion controller and drives.
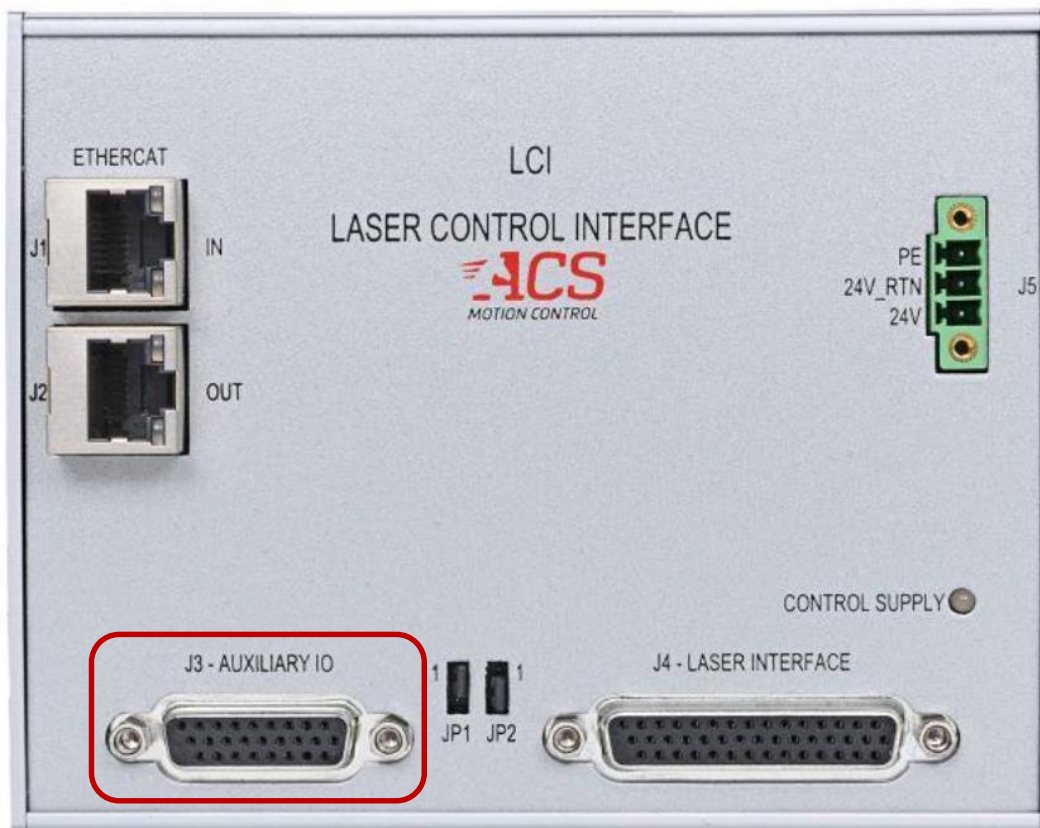
For more detailed information, please refer to
https://acsmotioncontrol.com/products/laser-control/lci/

* : 1.25 msec. = 1.2 msec. + 0.05 msec., where 1.2 msec. is the preview time of *SCAN*ahead control and 0.05 msec. is the time required for signal transfer between RTC6 and the servo-driver electronics inside the excelli*SCAN*.

Solution by emulated / virtual encoder signals

Wiring between LCI and RTC6:

Encoder signal interface of RTC5/6
Pin-out of the (on-board) MARKING ON THE FLY socket connector

+5 V	(1)	(2)	GND
ENCODER X1−	(3)	(4)	ENCODER X1+
ENCODER X2−	(5)	(6)	ENCODER X2+
ENCODER Y1−	(7)	(8)	ENCODER Y1+
ENCODER Y2−	(9)	(10)	ENCODER Y2+
/STOP2	(11)	(12)	/START2
BUSY OUT	(13)	(14)	ANALOG OUT2
GND	(15)	(16)	NOT CONNECTED

J3 Auxiliary IO of LCI

Solution by emulated / virtual encoder signals

Wiring between LCI and RTC6:

Axis	Signal	J3 - LCI Pin No.	RTC6 MOTF Pin No.
X	A+	#1(Output1+)	#4(X1+)
	A-	#10(Output1-)	#3(X1-)
	B+	#2(Output2+)	#6(X2+)
	B-	#11(Output2-)	#5(X2-)
	Shield	Case	
	DGND	#20	#2 or #5 (GND)

Axis	Signal	J3 - LCI Pin No.	RTC6 MOTF Pin No.
Y	A+	#3(Output1+)	#8(Y1+)
	A-	#12(Output1-)	#7(Y1-)
	B+	#4(Output2+)	#10(Y2+)
	B-	#13(Output2-)	#9(Y2-)
	Shield	Case	
	DGND	#20	#2 or #5 (GND)

+5 V (1) — (2) GND
ENCODER X1– (3) — (4) ENCODER X1+
ENCODER X2– (5) — (6) ENCODER X2+
ENCODER Y1– (7) — (8) ENCODER Y1+
ENCODER Y2– (9) — (10) ENCODER Y2+
/STOP2 (11) — (12) /START2
BUSY OUT (13) — (14) ANALOG OUT2
GND (15) — (16) NOT CONNECTED

Encoder signal interface of RTC5/6
Pin-out of the (on-board) MARKING ON THE FLY socket connector

#9 #1
#26 #19

J3 Auxiliary IO of LCI

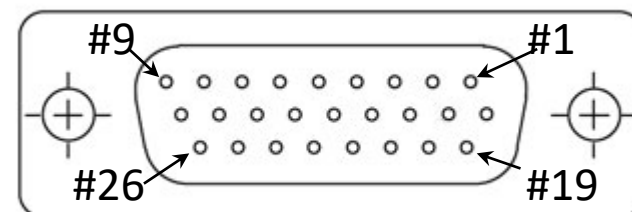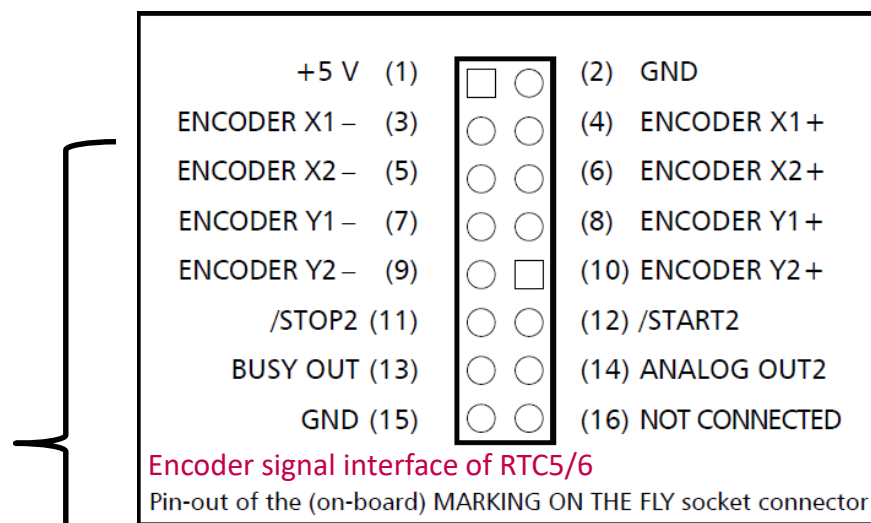# Solution by emulated / virtual encoder signals

Wiring between LCI and RTC6:

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	DGND	#20	#2 or #5 (GND)

+5 V	(1)	(2)	GND
ENCODER X1–	(3)	(4)	ENCODER X1+
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Encoder signal interface of RTC5/6
Pin-out of the (on-board) MARKING ON THE FLY socket connector

#9 #1
#26 #19

J3 Auxiliary IO of LCI
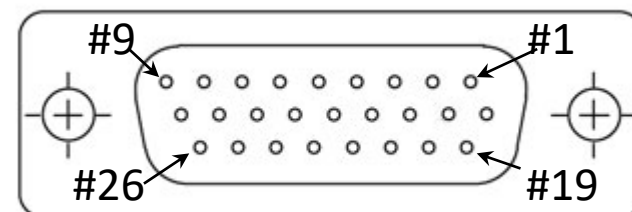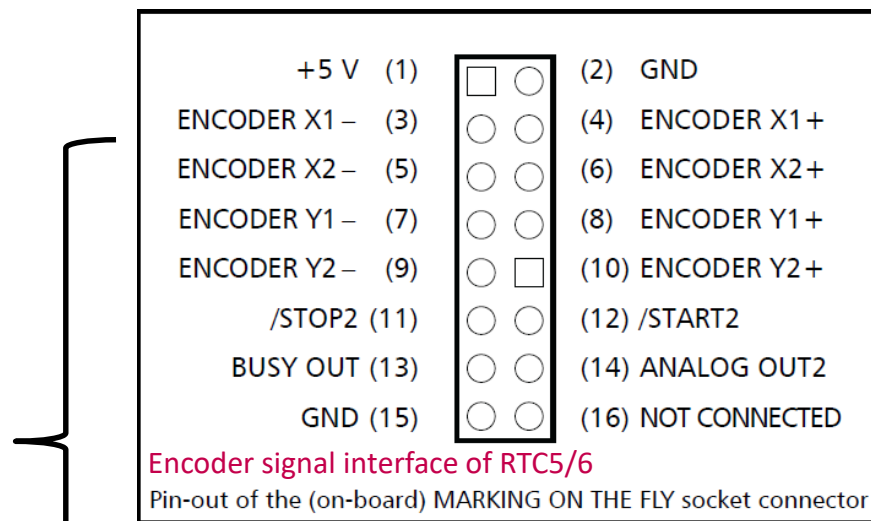
Solution by emulated / virtual encoder signals

RTC6 Programming:

What changes for the user, if LCI's emulated encoder signals shall be used for the FLY mode of RTC6 with excelli*SCAN?*

- Before FLY initialization, please apply **fly_prediction(PredictionX = 0, PredictionY = 0)** in order to deactivate the extrapolation for the prediction of encoder pulse counts.

- Applying **activate_fly_2d_encoder()** or **activate_fly_xy_encoder()** instead of **set_fly_*()** is recommended for FLY initialization. By doing so, the encoder counter values will not be reset to zero.

- Other than this, nothing changes for the users, so they can program their FLY applications just as usual.

Solution by emulated encoder signals
Merit offered by FLY with ACS motion controller + LCI and excelli*SCAN* + RTC6

- ACS motion controller and drives (with optimized tuning and configuration setting) allows for the **minimization of difference between the set trajectory and the actual trajectory of stage**.
  => Emulated enc. signals from LCI correspond to the <u>**set trajectory of stage**</u>.

- The emulated encoder signals also takes the stage's **error mapping data** into account.
  => No need to perform error mapping twice (once for stage motion control itself
      and another time for encoder signals fed into the RTC6 for the use of RTC6 command
      load_fly_2d_table)

- The emulated encoder signals can be **shifted along the time axis** (no matter, whether in positive or in negative direction)
  => The <u>**preview time**</u> of excelli*SCAN*'s *SCAN*ahead control does not pose any obstacle
      anymore.
  => The tracking-error-free scanner motion fully exploiting the dynamic potential
      of galvanometers can, now, be applied 2D FLY even for acc. / dec. stage motion.
  => High accuracy and high dynamics / productivity achievable both at the same time

Solution by emulated encoder signals
Drawback in comparison to XL *SCAN* / sync*AXIS*

- In case of MoF / PoF, the sync of the starting point in scanner motion and stage motion requires either External List Start or invoking the RTC command **wait_for_encoder**.
  => **10 µsec. jitter** is always present (for example, at stage speed of 1 m/s, this can cause position errors up to max. 10 µm)
  => But no such jitter present in XL *SCAN* / sync*AXIS*

- In case of excelli*SCAN* controlled by RTC6.dll scanner motion is only acceleration-limited and pre-calculation of scanner's motion trajectory is performed only piecewise along the time axis (i.e., within 1.2 msec. time window running over the input motion path).
  => Positioning accuracy and motion stability not as good as those achieved by XL *SCAN* / sync*AXIS* which works with complete traj. pre-planning and jerk-limited control

- Spot Distance Control (SDC) of RTC6.dll in FLY not as accurate as SDC of sync*AXIS*.dll
  => error contributions from the points stated above and from stage-encoder-based calculations in RTC6 for FLY correction of scanner motion

- Reduction of excelli*SCAN*'s acceleration limit possible only globally (i.e. for an entire job) in RTC6.dll, whereas syncAXIS.dll allows for locally varying setting.
  => concern for users aiming at extremely high accuracy and dynamics both at the same time