



Beyond existing specification tools

How to specify on a drawing an alignment specification using ISO GPS situation features

Dr Bertrand Nicquevert, CERN, EN department, Geneva, Switzerland

with the contribution of Fabien Rey, ESS, Lund, Sweden

This talk is a follow-up of an IWAA 2024 (SLAC) talk




école —————
normale —————
supérieure —————
paris – saclay —————

CoToLiP, a new tool to handle each of the six degrees of mutual situation between any two integral features

Dr Bertrand Nicquevert
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IWAA 2024 – International Workshop on Accelerators Alignment
Session « Tools and Monitoring II »
Stanford, California, USA – 7-11 October 2024






Laboratoire Universitaire de Recherche en Production Automatisée
4 avenue des Sciences 91190 Gif-sur-Yvette - France – <http://lurpa.ens-paris-saclay.fr>

... making reference to another IWAA 2024 talk by F. Rey

Behind the curtain of “Engineering to Alignment”

This talk can be seen as a complement, an introduction, or the theoretical background of our talk from IWAA 2024 (Tuesday 10/08 1:30pm PT):

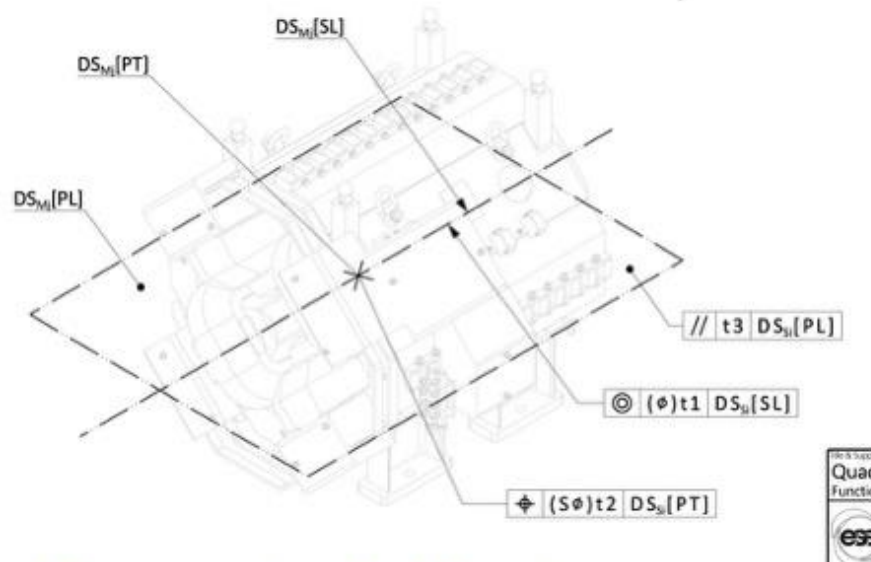


EUROPEAN SPALLATION SOURCE

From Engineering to Alignment :

On the use of installation specifications based on an extended use of ISO GPS situation features

FABIEN REY
BERTRAND NICQUEVERT



“Behind the curtain” of the creation of the generic set of drawings for functional definition, fiducialization and installation

2024-10-10, B. Nicquevert, IWAA 2024

... where the “ToLiP” was used for installation drawings



3. Datum Systems at ESS

1. ToLiP

ISO 5459:2011 Geometrical product specifications (GPS) – Geometrical tolerancing – Datums and datum systems

ISO 5459:2024

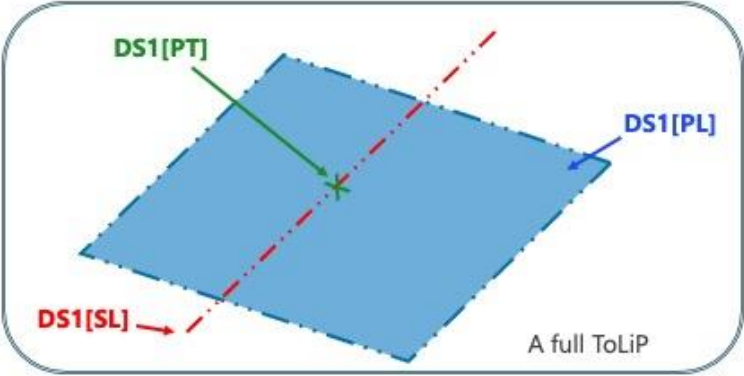
A datum system can always be reduced to a resulting minimal set, made of :

a theoretically exact plane **[PL]**
a straight line **[SL]** in this plane,
and a point **[PT]** on this straight line
(locking all degrees of freedom)

OR
a subset of those
(locking 3 to 5 degrees of freedom)

This resulting datum system may be called a

“ToLiP”: Point**T** on Line in Plane.



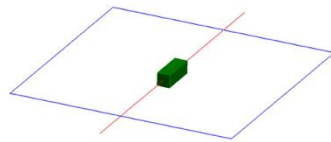
ON THE USE OF INSTALLATION SPECIFICATIONS BASED ON AN EXTENDED USE OF ISO GPS SITUATION FEATURES – FABIEN REY

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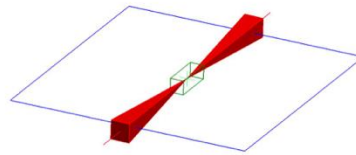
... itself following up his IWAA 2022 (Ferney) talk, whose provisional conclusion yielded to the following representation of “*tolerances*”:



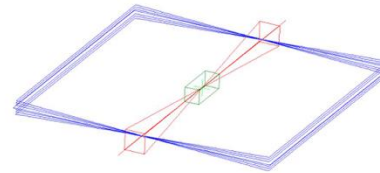
Thank you



ΔPT



ΔSL



ΔPL

Dr Bertrand Nicquevert



Fabien Rey



Today's talk is an *update* on these “tolerances”, and on the specifications that may capture them in a TPD*

TPD: Technical Product Documentation
= a drawing, or an annotated 3D model

A contribution to a solid definition of the “*alignment requirements*”

Table tolerances: on the value of which characteristic?

Typical example of alignment specification

Table 1. Specifications for magnets and girders alignment in modern light sources around the world. Each element is misaligned randomly in a Gaussian distribution with given RMS amplitude σ . Where NA⁺ corresponds to Not Applicable and NA* corresponds to Not Available.

Machine	E (GeV)	C (m)	Magnet-to- magnet (μm)	Cut-off (±σ)	Girder-to- girder (μm)	Cut-off (±σ)
ALS-U	2	196.5	10	2	50	2
APS-U	6	1103.608	30	2	100	1
Diamond-II	3.5	560.574	25	2	150	2
ESRF-EBS	6	843.97	60	2.5	NA ⁺	NA ⁺
NSLS-II	3	792	30	1	100	1
SIRIUS	3	518.4	40	1	80	1
MAX-IV	3	528	20	1	NA*	NA*
SOLEIL-II	2.75	353.74	30	2	50	2

“Magnet-to-magnet”?
A magnet is not just a point, is it?
And what is this thing called “girder to girder”?

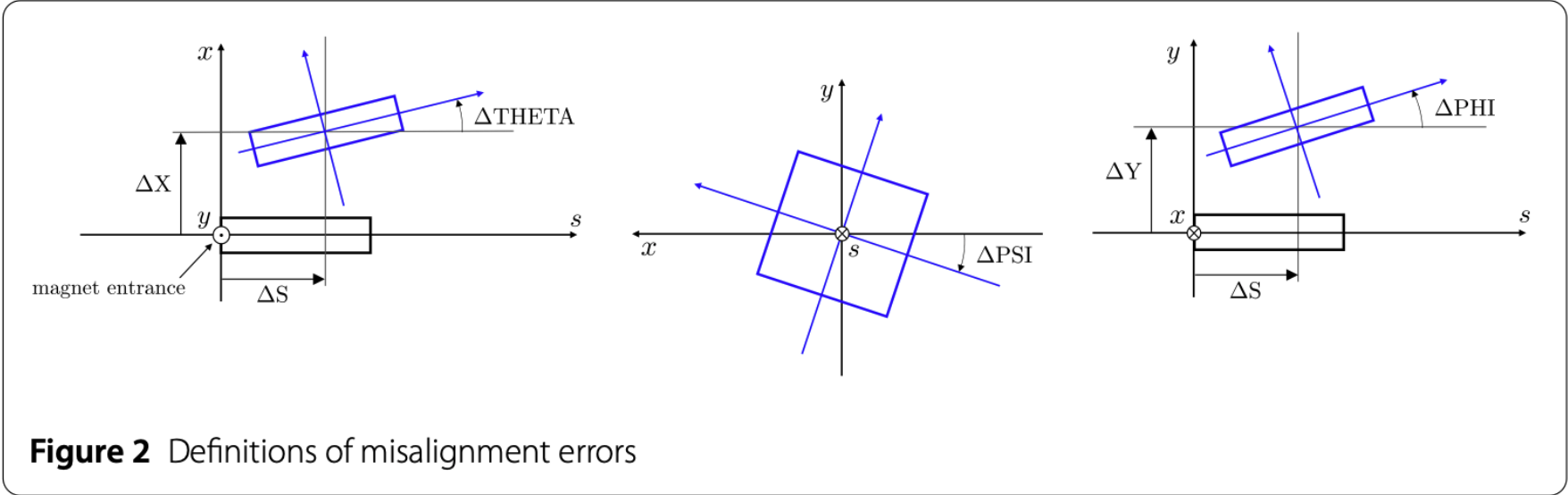
13th International Particle Accelerator Conference (IPAC’22) IOP Publishing
Journal of Physics: Conference Series 2420 (2023) 012055 doi:10.1088/1742-6596/2420/1/012055

Angular specifications: a more illustrated case

Type	$\Delta X (\mu m)$	$\Delta Y (\mu m)$	$\Delta PSI (\mu rad)$	$\Delta S (\mu m)$	$\Delta THETA (\mu rad)$	$\Delta PHI (\mu rad)$
Arc quadrupoles*	50	50	300	150	70	70
Arc sextupoles*	50	50	300	150	70	70
Dipoles	1000	1000	300	1000	0	0
Girders	150	150	–	1000		
IR quadrupole	100	100	250	250	70	70
IR sextupoles	100	100	250	250	70	70

Charles et al. EPJ Techniques and Instrumentation (2023) 10:8
<https://doi.org/10.1140/epjti/s40485-023-00096-3>

* misalignments relative to girder placement



Is everything explicitly defined?

- What is the tolerated feature? Is it a center? Or also an axis? Or even a plane? Or all?
- Defined how?
 - By its geometrical surfaces? by its functional situation features? (e.g. for a magnet, by the magnetic axis after fiducialization)
- What are the characteristics on which these conditions apply
 - Based on the actual (measured) value of what? What is meant by “girder placement”?
- Accessorily, how is roll angle defined, and what is the order of composition of rotations?
 - Undetermined, and only depending on the nominal axes (by projection)?
 - Or with an order? Phi - theta - psi? Phi Psi theta? Theta Psi phi? ... (6 possibilities)

And how to indicate these specification univocally on a drawing?

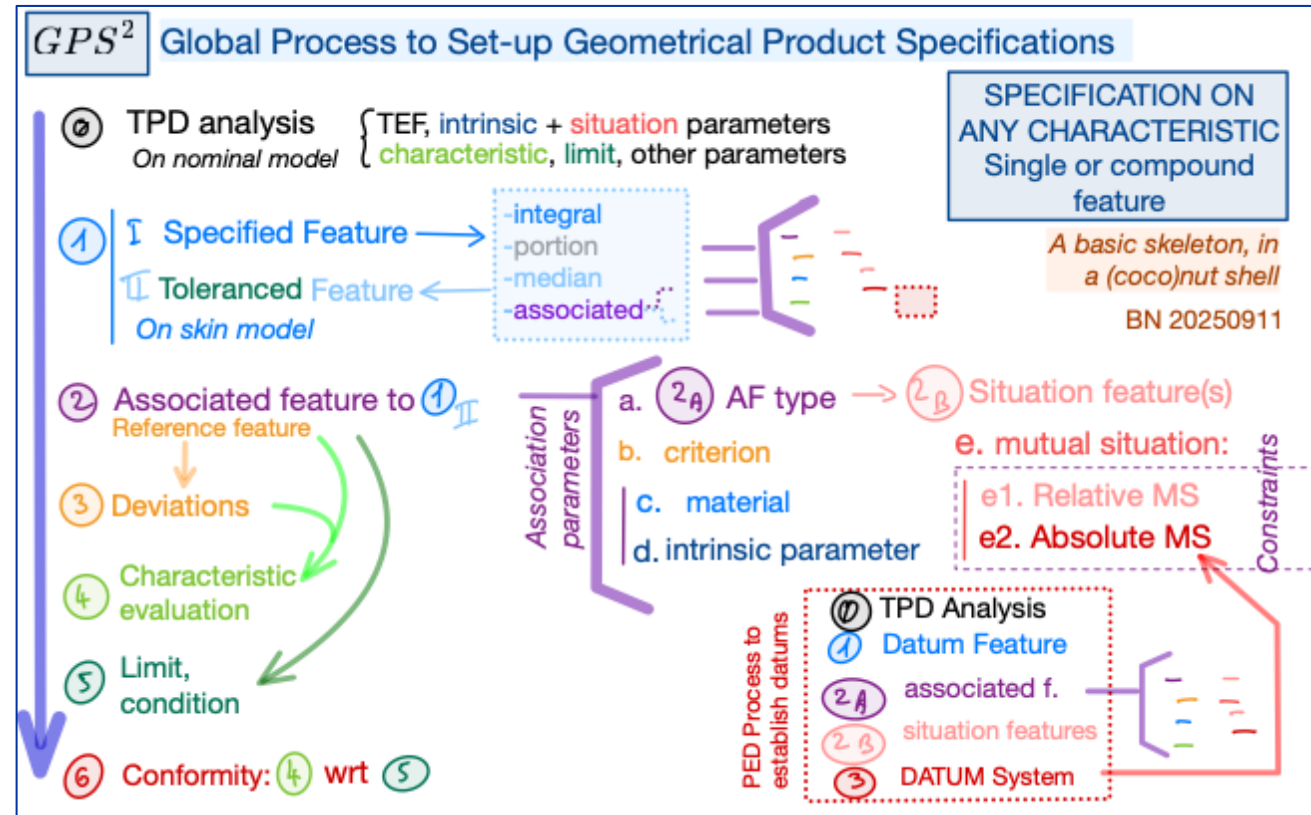
This, with the aim to bridge the various communities: the user's requirement, the functional specification, the assembly instruction (alignment requirements), the verification specification (survey), and also the machining, the fiducialization...

An overall “specification process” was developed for ISO

GPS^2: Global Process to Set-Up Geometrical Product Specifications

0. nominal specified features
nominal toleranced features (when ≠)
situation features of all these features
1. real specified features
real **toleranced** features
situation features of all these features
2. Associated theoretically exact features -> **reference feature**
3. Deviations between 1 and 2
4. Characteristic established on 3.
5. Limit condition on 4.

GPS^2 model considers *all* kinds of specifications
For illustration only - Extents **far** beyond the scope of today's talk...



... and **far** beyond our (alignment) needs!

Focussing on a “situation specification” in ISO GPS system

Probably equivalent to the so-called “frame requirement”

Situation specification (ISO 17450-1)

With respect to a feature of defined target situation (= with some or all distances and angles fixed by TEDs, Theoretically Exact Dimensions) with respect to a datum system, **the characteristic based on the deviations of the real feature shall not be greater than predefined agreed values: the *tolerances***

Situation features (ISO 17450-1 – definition, ISO 20223 – representation): as generalization of the “axis” of a cylinder, situation features are of type plane, straight line and points, preferably regrouped into a minimum set of situation features (MiSSiF) made of at most one plane, at most one straight line and at most one point, with the ToLiP condition “**point on line in plane**”

Situation of a feature (ISO 25378): the situation of any feature is defined by the situation of its situation features. => **Degrees of freedom of a feature = those of its situation features**

Complete situation specification: where **ALL** degrees of freedom (all distances and angles) of the nominal toleranced feature are constrained with respect to a datum system

Supporting paper of our IWAA 2024 talk published in *June*!

IOP Publishing

Meas. Sci. Technol. 37 (2026) 235006

<https://doi.org/10.1088/1361-6501/ae7140>

Measurement Science and Technology



PAPER

OPEN ACCESS

RECEIVED
4 December 2025

REVISED
11 May 2026

ACCEPTED FOR PUBLICATION
21 May 2026

PUBLISHED
10 June 2026

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Establishing and situating the functional features of the components of a particle beam based assembly using ISO GPS situation features

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Keywords: situation features, ISO GPS geometrical specifications, survey and alignment, magnetic measures, mutual situation, complex assembly, scientific facility

Overall process of a complete situation specification

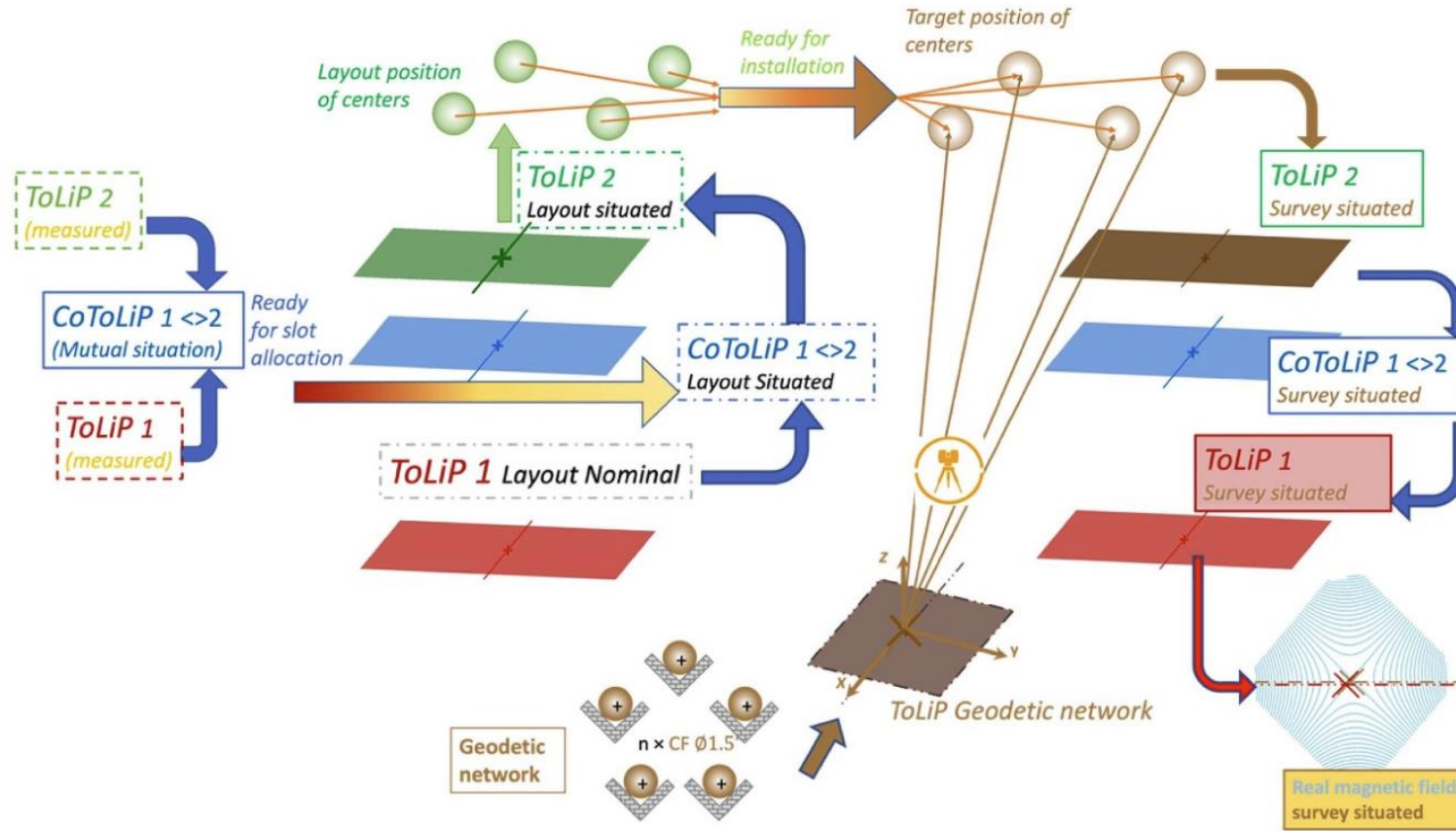


Figure 24. Installation phase of the overall process for handling the functional features using the situation features throughout the quadrupole magnet lifecycle. Left: slot allocation; right: installation and survey. Final output: a real magnetic field 'survey situated', i.e. installed to its nominal situation within the allowed tolerance of 30 μm (comparable to light sources [6]).

A complex, but not complicate **process!**

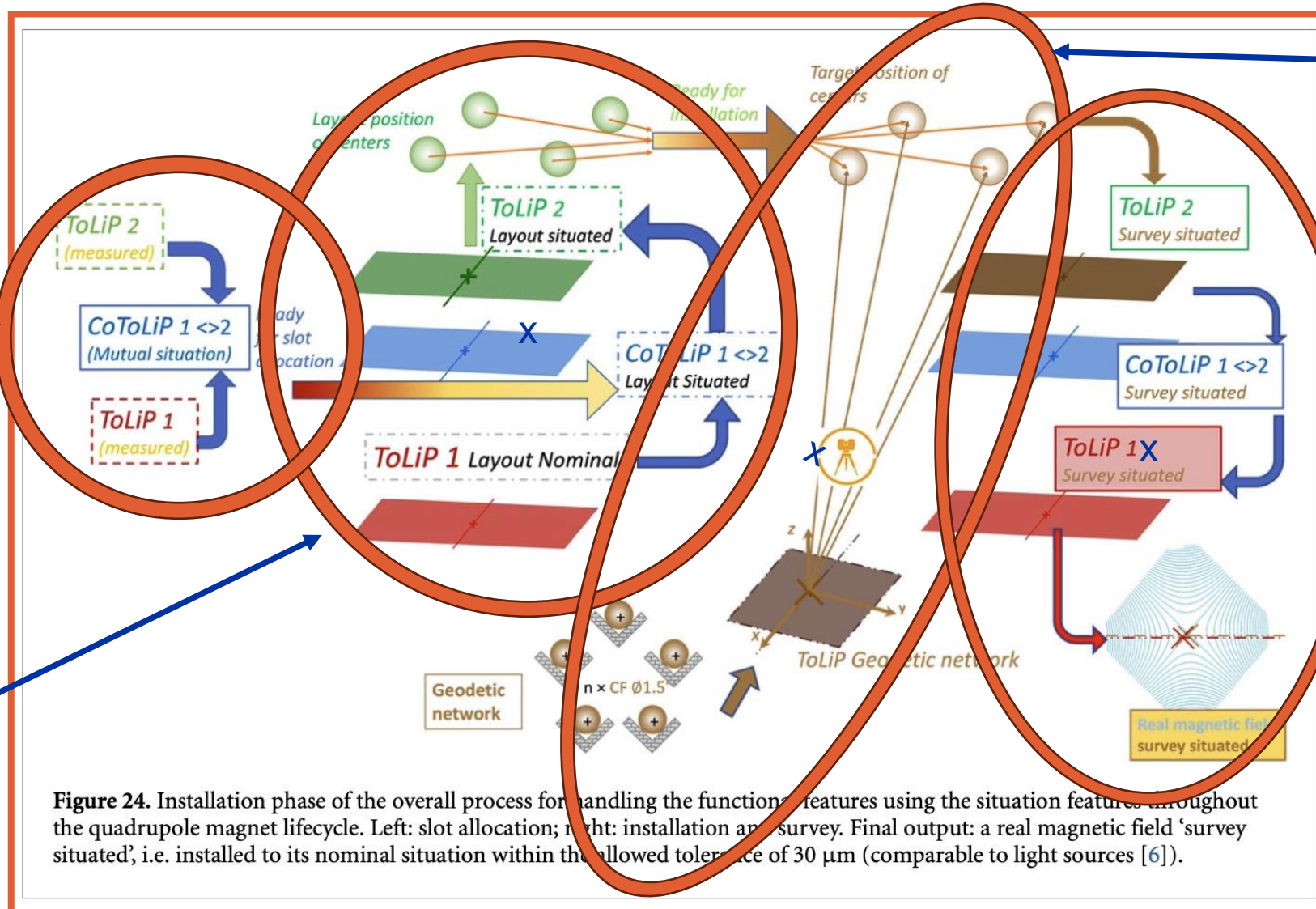
It deals altogether with:

- the situation features of
 - Nominal features;
 - Real features;
- of both:
 - The device itself;
 - Its functional features;
 - Its measured or surveyed features;
- during various sequential phases:
 - Fiducialization;
 - Specification;
 - Survey;
 - Alignment;
 - (and manufacturing, not shown here)

Four global steps

Fiducialization:
establishment of
“real” situation
features

**Specification of
the nominal
situation of the
situation features**



Verification:
survey of the
real situation of
the situation
features

**Alignment of
the real situation
of the situation
features with
respect to their
nominal situation**

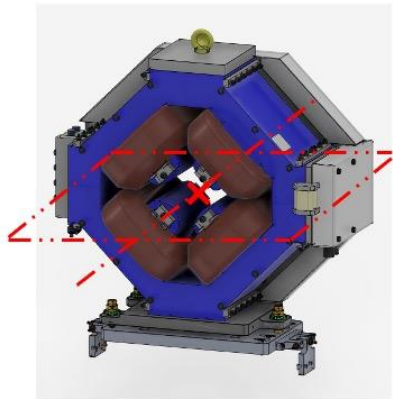
First step: establishment of situation features

(not the main topic for today: see IWAA 2024)

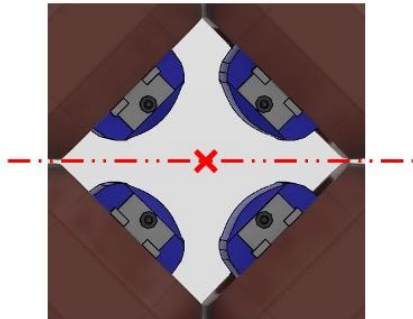
“Situation features”: how to characterize the situation



□ For a ESS quadrupole: magnetic axis? Magnetic center? Polarization plane?



Pole “profile”: invariance class **complex** (convex surfaces)



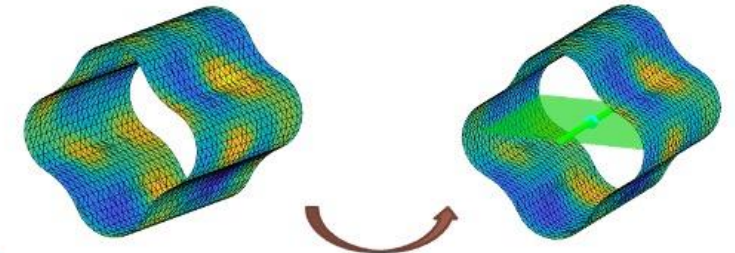
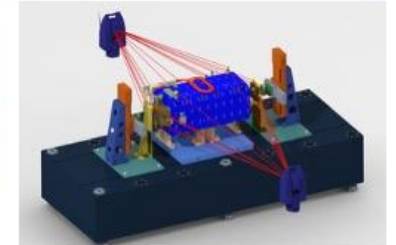
=> Minimum set of situation features: [ToLiP]

Invariance class complex and choice of situation features



- Obtained by association between nominal and real features
- When the nominal is not known, we can use a Laplace-Beltrami Operator: it gives the first “rigid body” modes even if nominal is not known
- Actually any choice of situation feature is agreeable, provided that the situation features are:
 - Meeting the ToLiP condition “Point on a Line in a Plane”
 - Explicitly represented on the TPD

Or, by fiducialization, by association between the nominal and the real magnetic field!



Situation features determination for a geometrical feature of prismatic invariance



2024-10-10, B. Nicquevert, IWAA 2024

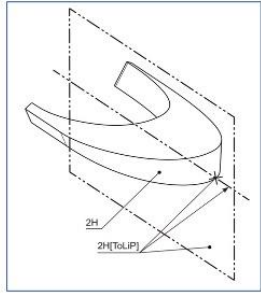


2024-10-10, B. Nicquevert, IWAA 2024

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Nominal situation features: ISO 20223 published in *July*!

An ISO standard to represent and identify situation features



Technical product documentation (TPD) — Representation and identification of situation features

Documentation technique des produits (DTP) — Représentation et identification des éléments de situation

ICS: 01.110

DRAFT
International
Standard

ISO/DIS 20223

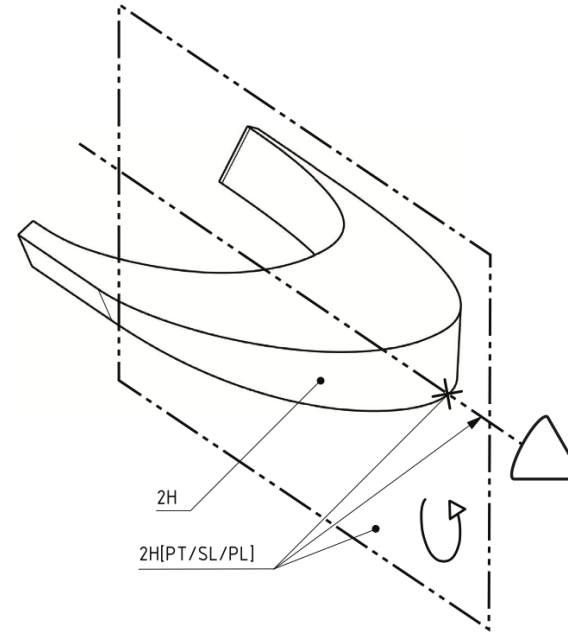
ISO/TC 10/SC 1

Secretariat: BSI

Voting begins on:
2024-09-13

Voting terminates on:
2024-12-06

- A project developed starting from ESS and CERN needs
- Currently under public consultation
- Please send your comments through your national committee
- AFNOR, ASME, BSMI, BS, DIN, DS, JISC, SAC, SCC, SIS, SNV, UNE, UNI...
- Deadline: by end of November = now!



b) Representation and identification with indication of the positive directions

International
Standard

ISO 20223

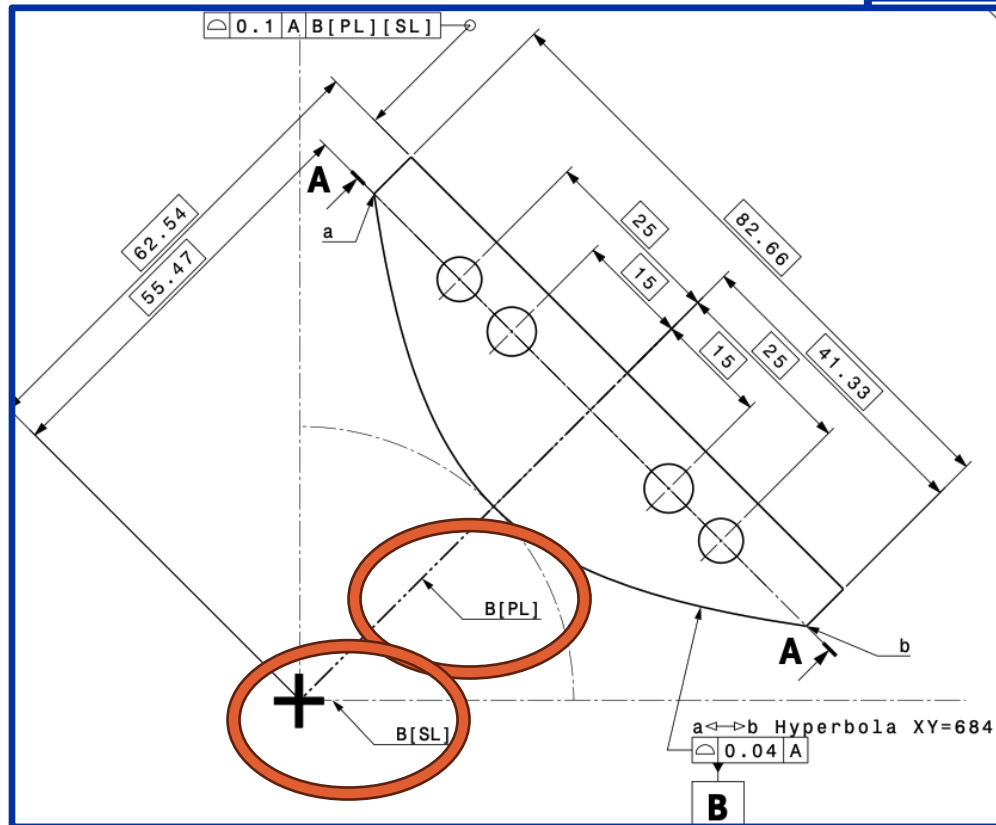
First edition
2026-07

Provides (hopefully) all tools to represent the nominal situation features

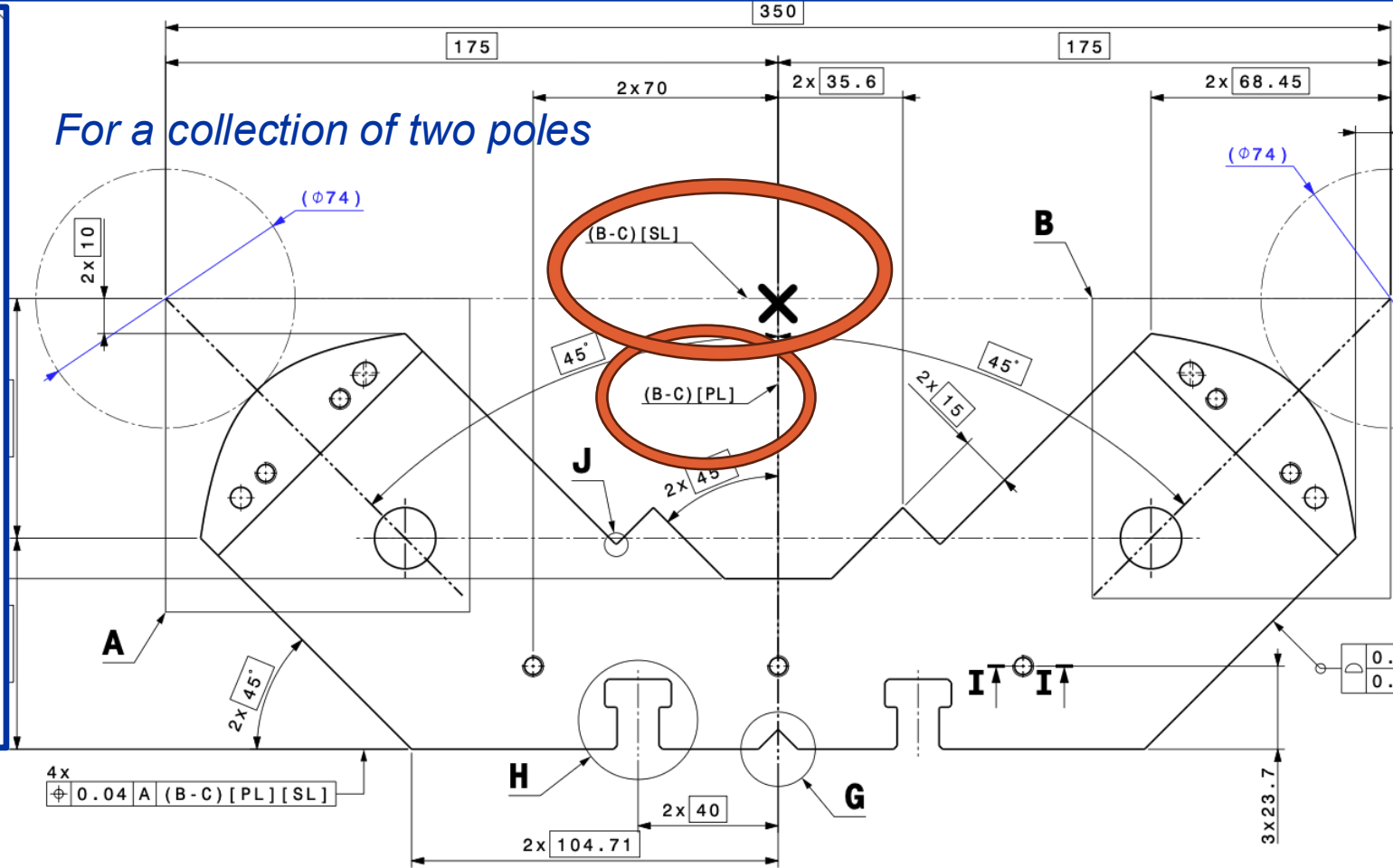
Technical product documentation (TPD) — Representation and identification of situation features

Documentation technique de produits (DTP) — Représentation et identification des éléments de situation

Example of an explicit indication of situation features: the prototype of FCC-ee quadrupoles



For one hyperbolic pole



Mutual situation: a key topic

Katerina Kamprani, *Objets inconfortables*
MuAM, oct. 2025



NWI = New Work Item
This a **new ISO standard** on the topic,
currently under (very first stage of) preparation

ISO/NWI 25431:2025(E)

ISO TC 213/ WG 14

Date: 2026-08-31 – v.3

Expectation for today: capture
the needs of IWAA community,
to provide in this ISO 25431
the tools we are in need for

Geometrical Product Specifications (GPS)— Mutual situation

Spécifications géométriques des produits – Situation mutuelle

CoToLiP, a tool proposed to parametrize the mutual situation

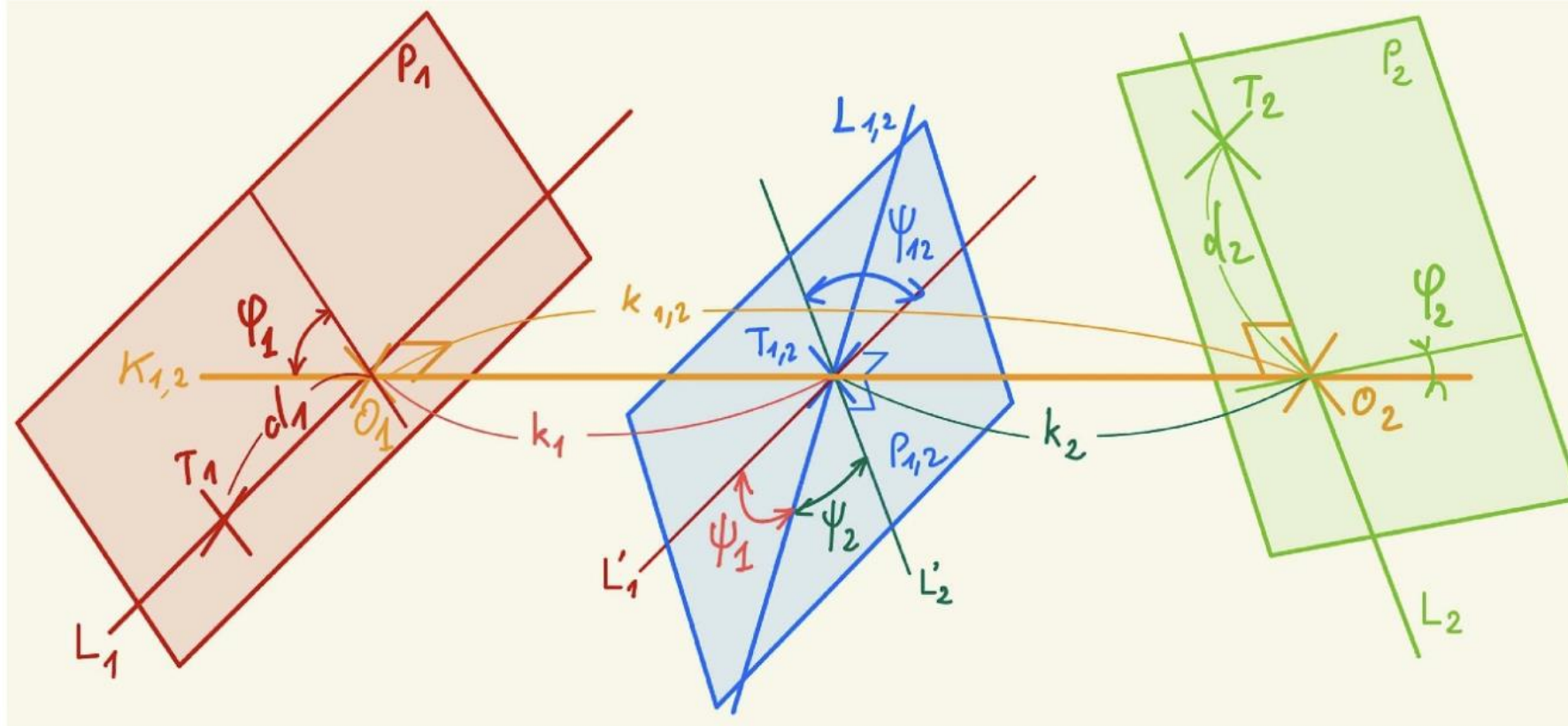


Figure 4. A definition of the CoToLiP (in blue in the middle) of two complete ToLiPs (in red and in green, respectively) (revised and completed from [2]). The CoToLiP is a set made of a ToLiP (here a complete ToLiP) and of six parameters of mutual situation: mutual location $d_1, d_2, k_{1,2}$ and mutual orientation $\varphi_1, \varphi_2, \psi_{1,2}$.

First published in a simpler form @IPAC 2023

Can serve to parametrize the mutual situation of **any pair of ToLiPs** (minimum sets of situation features)

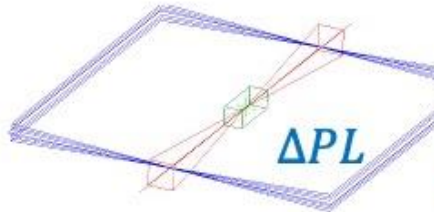
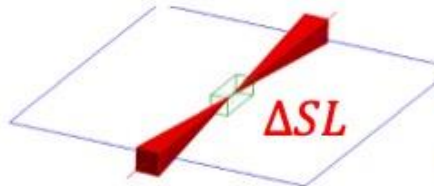
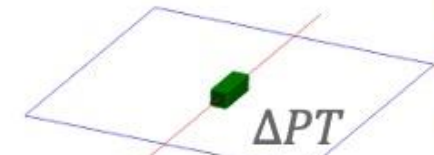
- Complete ToLiPs, with all three types
- ToLiPs with remaining internal mobilities (degrees of freedoms)
- Two ToLiPs of ideal features
- Two ToLiPs of real features
- Or real vs ideal

Handling deviations?

Perspective 3: handling deviations



From IWAA2022



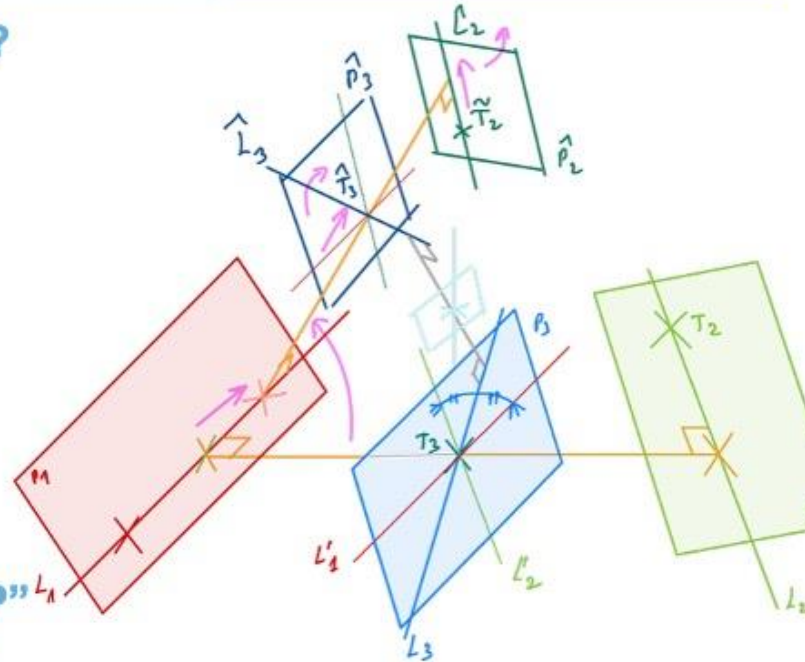
Assess the deviations?
by using the CoToLiP
between:

- the CoToLiP of
nominal absolute
mutual situation

and

- the CoToLiP of the
actual absolute
mutual situation

This is the “CoCoToLiP”
and its six parameters
 $\partial x, \partial y, \partial z, \partial u, \partial v, \partial w$



For IWAA 2026

In 2024, the results of
our research were not
yet converging
*Where are we with
this topic in 2026?*

CoCoToLiP? Handling deviations of a CoToLiP

Aim: evaluation of the *deviation* between nominal and real situations

Let us define, for our case:

- **ToLiP0** = ToLiP of a resulting datum system
- **ToLiP1** = ToLiP of the specified feature (functional features)
- *Nominal situation* of **ToLiP1**: represented by a **CoToLiP 1, 0** between this **ToLiP1** and **ToLiP0**
- **ToLiP2** = ToLiP of the same specified feature with deviations
- *Actual situation* of **ToLiP2**: represented by a **CoToLiP 2, 0** between this **ToLiP2** and **ToLiP0**
- “CoCoToLiP” represents the “variation”, or “deviation” of the initial **CoToLiP 1, 0**
- CoCoToLiP is also... *a CoToLiP!*
 - This is **CoToLiP 2,1** representing the deviations between the nominal *specified* **CoToLiP1,0** and the actual *measured/surveyed* **CoToLiP 2, 0**
- **Target for *alignment*: make CoCoToLiP = 0: “cancel deviations”, both in translation and in rotation**

There are so many ToLiPs and CoToLiPs involved that this is hard to catch them all !

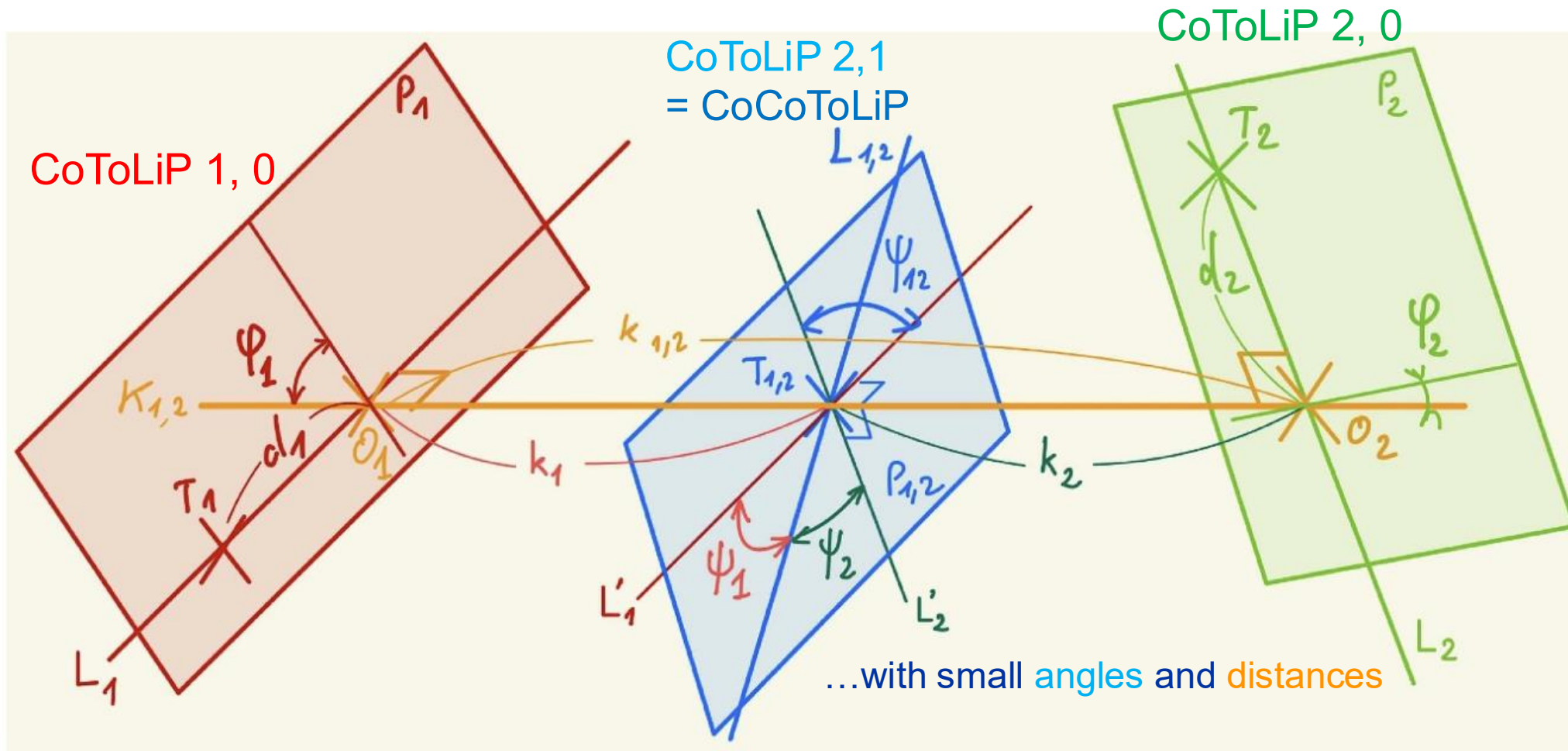


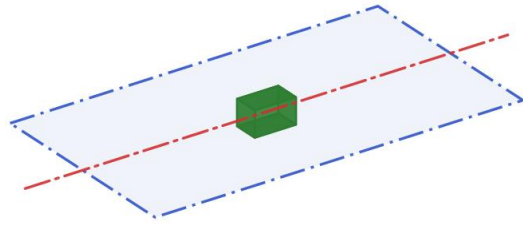
Figure 4. A definition of the ~~CoToLiP~~ (in blue in the middle) of two complete ~~ToLiPs~~ (in red and in green, respectively) (revised

CoCoToLiP

CoToLiPs

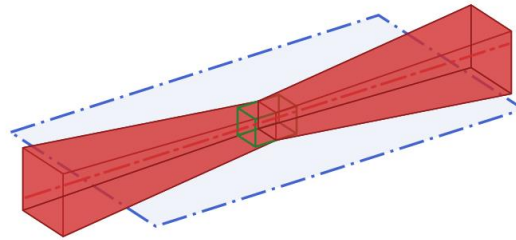
A fractal perspective! Self-similarity at every scale

First attempt (IWAA 2022) of a “CoCoToLiP” representation



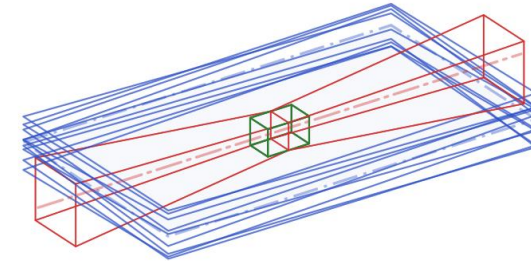
ΔPT

The three translations were represented by the three translational mobilities of the point [PT]



ΔSL

The two rotational mobilities of the straight line [SL] around the point [PT] were representing two of the three rotations

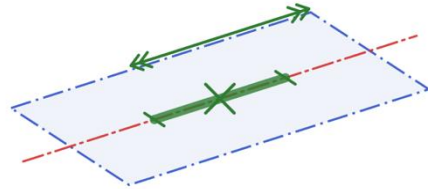


ΔPL

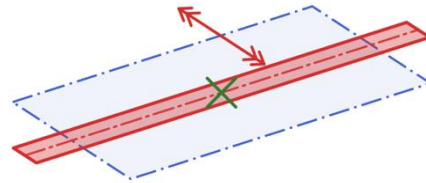
The rotational mobility of the plane [PL] around the straight line [SL] was representing the last of the three rotations

Second variant (today's IWAA 2026), using ISO 20223 annex B

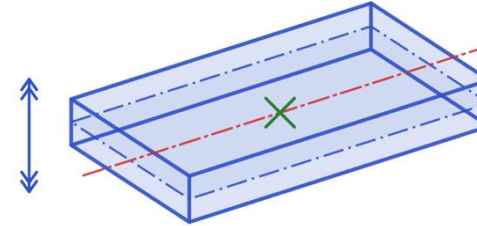
Translations



sliding [PT] along [SL]
sToL

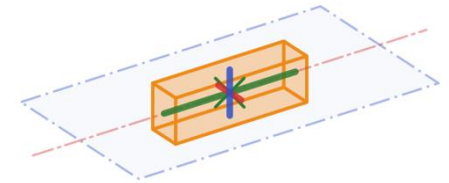


sweeping [SL] in [PL]
sLiP



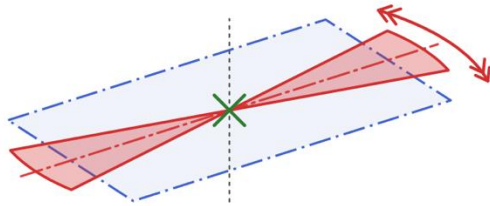
shifting [PL]
sP

Adding them all up:

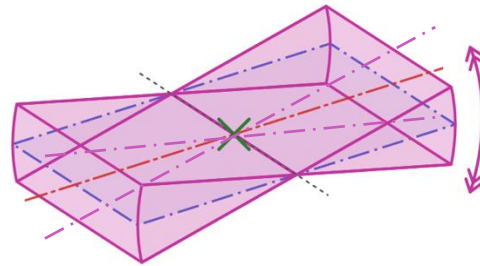


swimming [PT]
(composition of the three translations)
Would be the same for any point

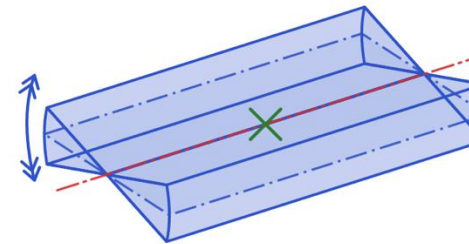
Rotations



rotating [SL] in [PL]
around [PT]
rLiP%T
angle "L"



rocking plane [SL]/[PL]
around a line passing by [PT]
perpendicular to [SL]
R(L,P)%T
angle "LP"



revolving [PL]
around [SL]
rP%L
Angle "P"

Nota: denominations are
not yet standardized!
Follow the development of
ISO/NWI 25341

How to add all this up?
*Not the same result for
any point!*

L, P, LP: provisional notations

Based on indication of degrees of freedom of any MiSSiF*

* MiSSiF: Minimum Set of Situation Features; can be complete or not

Table B.1 — Representation of generic intrinsic translational mobilities

ISO 20223:2026

Table B.2 — Generic representation of intrinsic rotational mobilities

Translational mobility	2D representation		3D representation	Representation in annotation planes
	Front view	End view		
	Top view			
1. Of the situation feature of type [PT] along the situation feature of type [SL]				
2. Of the situation feature of type [PT] inside the situation feature of type [PL]				
3. Of the situation feature of type [SL] inside the situation feature of type [PL]				

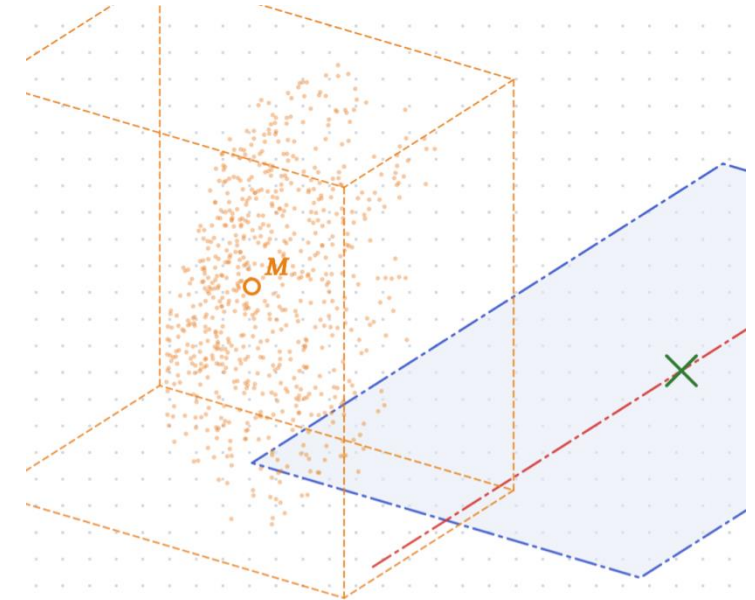
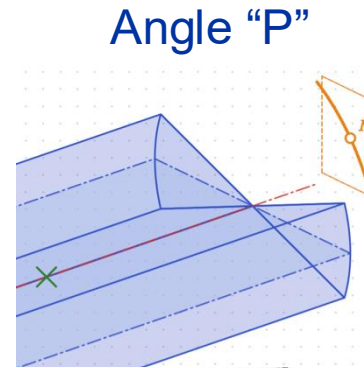
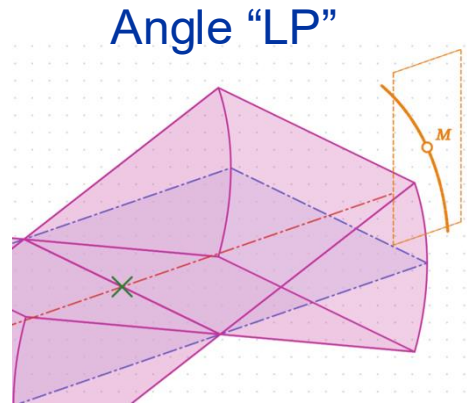
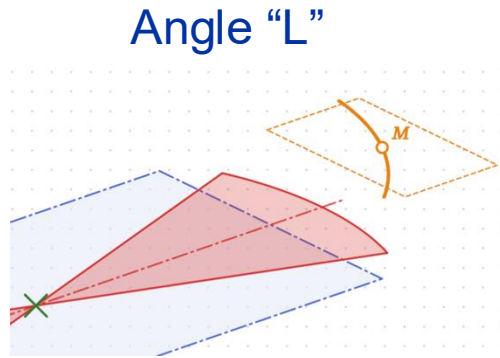
NOTE The representations in this table are generic. They can be combined, either together or with the representations of [Table B.2](#).

Rotational mobility	2D representation		3D representation	Representation in annotation planes
	Front view	End view		
	Top view			
1. Of the situation feature of type [SL] over the situation feature of type [PT]				
2. Of the situation feature of type [PL] over the situation feature of type [PT]				
3. Of the situation feature of type [PL] around the situation feature of type [SL]				

NOTE The representations in this table are generic. They can be combined, either together or with the representations of [Table B.2](#).

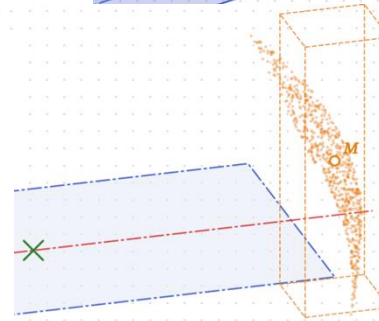
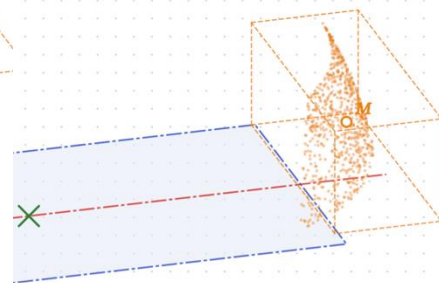
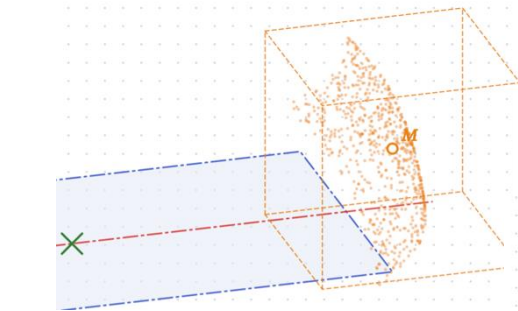
Visualization of the combination of mobilities at any point

Influence of the variation of the angles on the position of the point M



All angles "L", "LP" and "P"

When these mobilities are uncertainties on the value of each angle, their total contribution on the final position of any point M is here visualized (Nota: adding up translations is trivial – they are not represented here)



CoToLiPian angles (angular parameters of a CoToLiP)

Definition of the linear and angular parameters

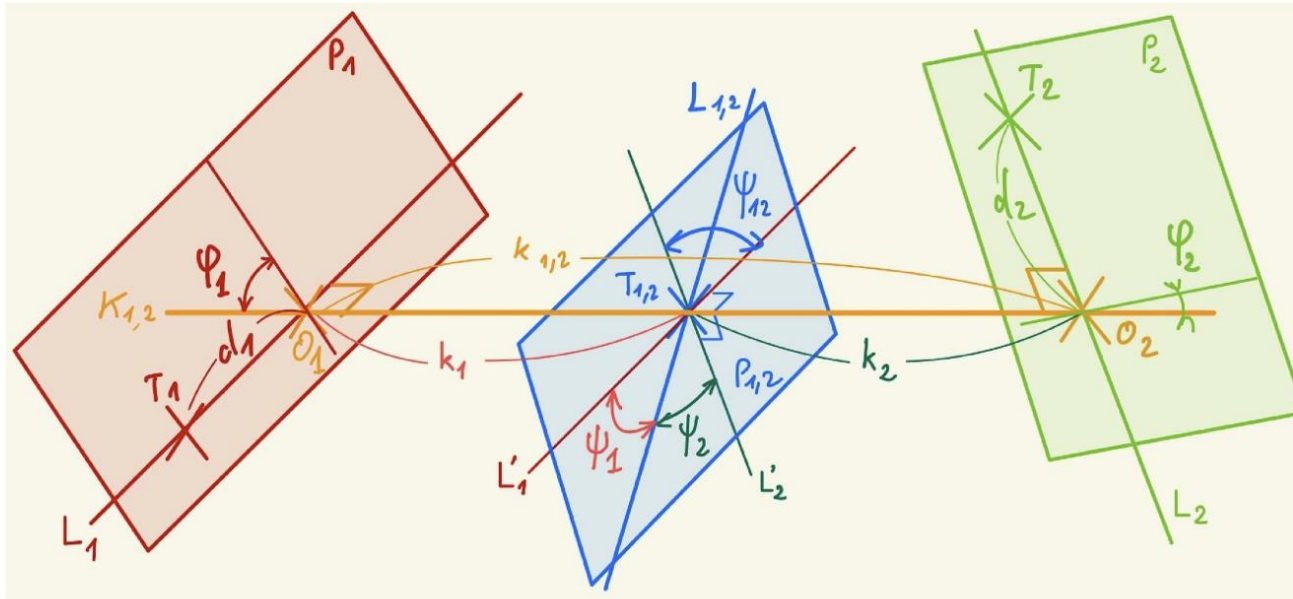
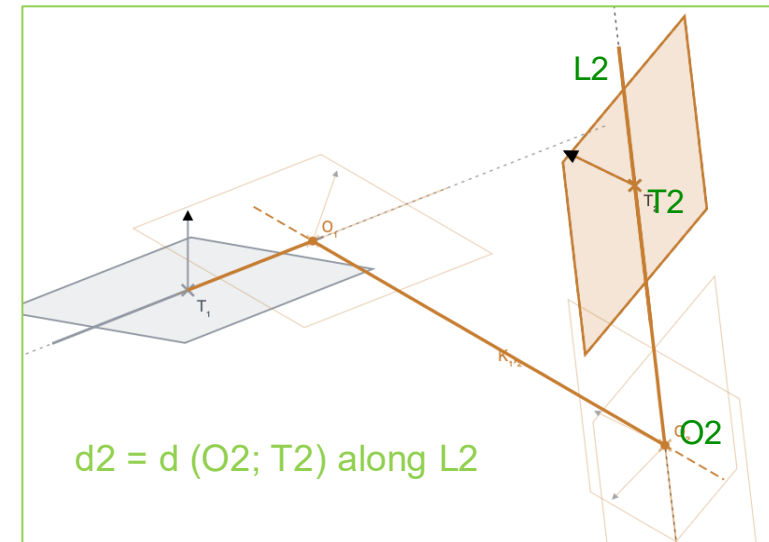
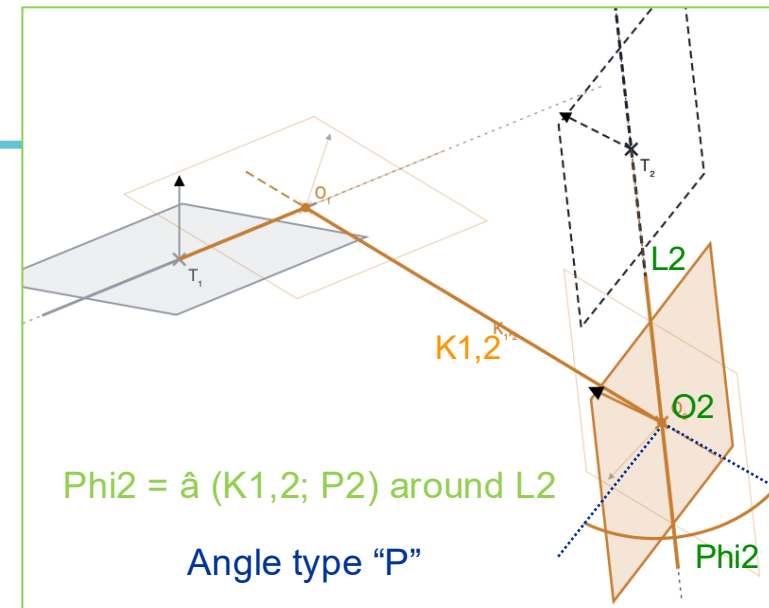
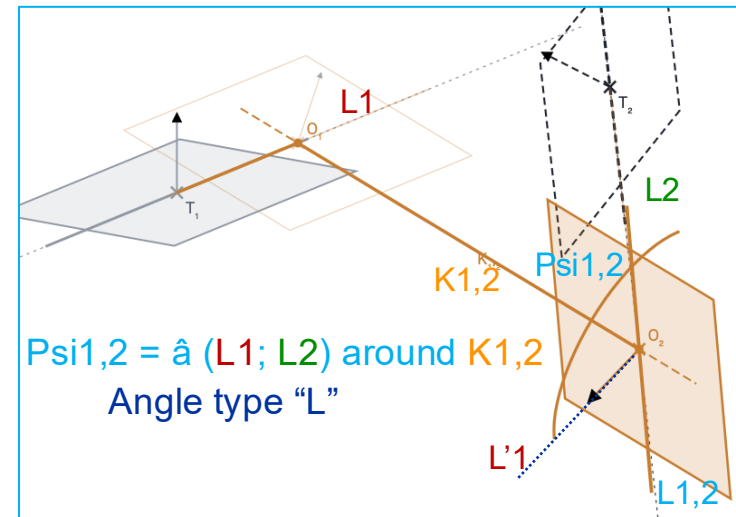
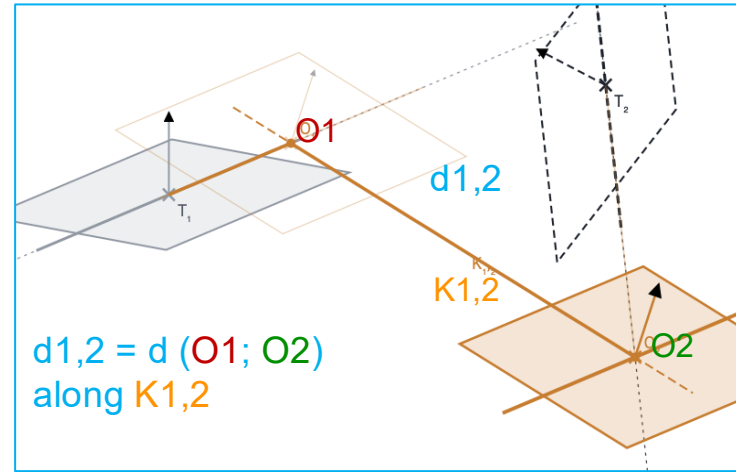
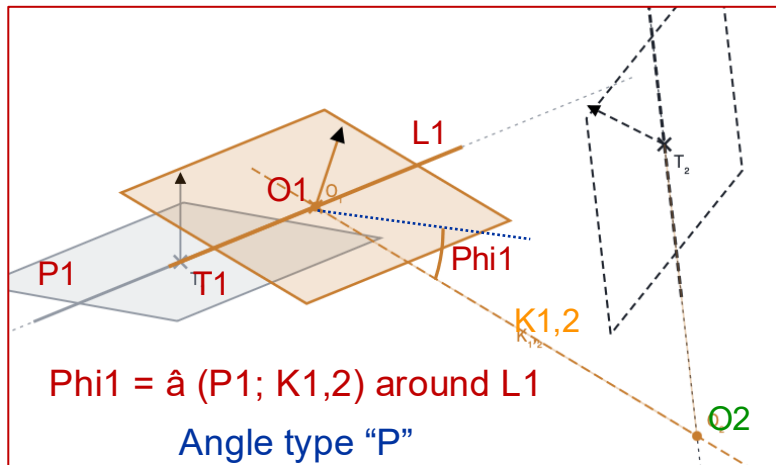
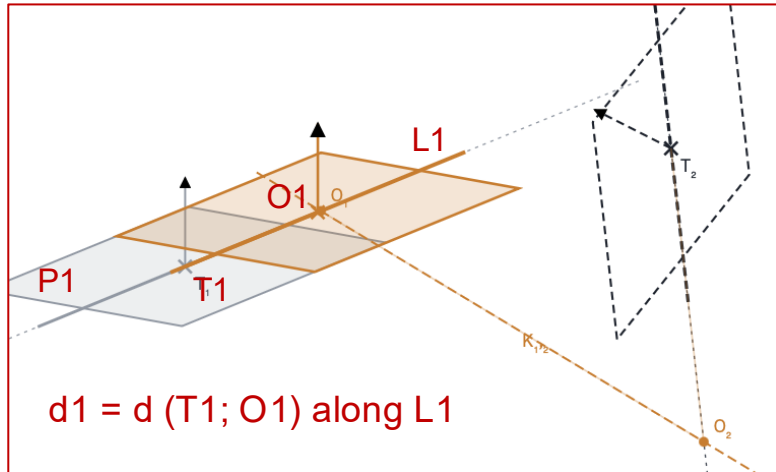


Figure 4. A definition of the CoToLiP (in blue in the middle) of two complete ToLiPs (in red and in green, respectively) (revised and completed from [2]). The CoToLiP is a set made of a ToLiP (here a complete ToLiP) and of six parameters of mutual situation: mutual location d_1 , d_2 , $k_{1,2}$; and mutual orientation φ_1 , φ_2 , $\psi_{1,2}$.

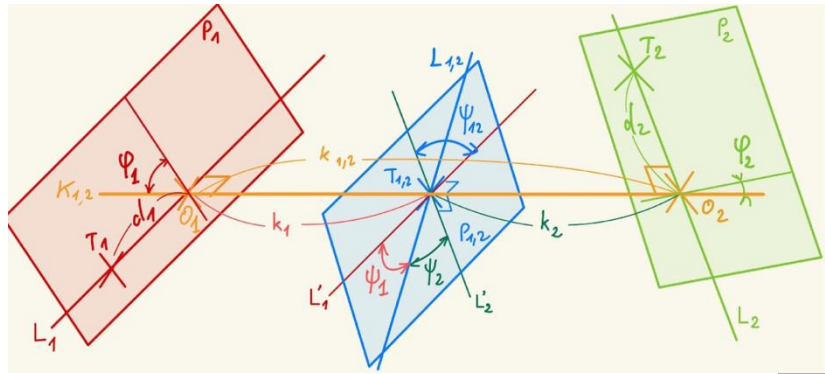
- $d_i = d(T_i; O_i)$ along L_i ;
- $k_{1,2} = d(O_1; O_2) = k_1 + k_2$ along $O_1 O_2 = K_{1,2}$;
- $\varphi_1 = (\widehat{K_{1,2}; P_1})$ (around L_1);
- $\varphi_2 = (\widehat{K_{1,2}; P_2})$ (around L_2);
- $\psi_{1,2} = (\widehat{L_1; L_2}) = \psi_1 + \psi_2$ around $O_1 O_2 = K_{1,2}$.

Equivalent to **Euler angles**
of type $x - z' - x''$
(or $x_1 - z_2 - x_3$)

CoToLiPian transformation steps



Focus on the angular parameters (after translations)



CoToLiPian angles

Phi1

Psi1,2

Phi2

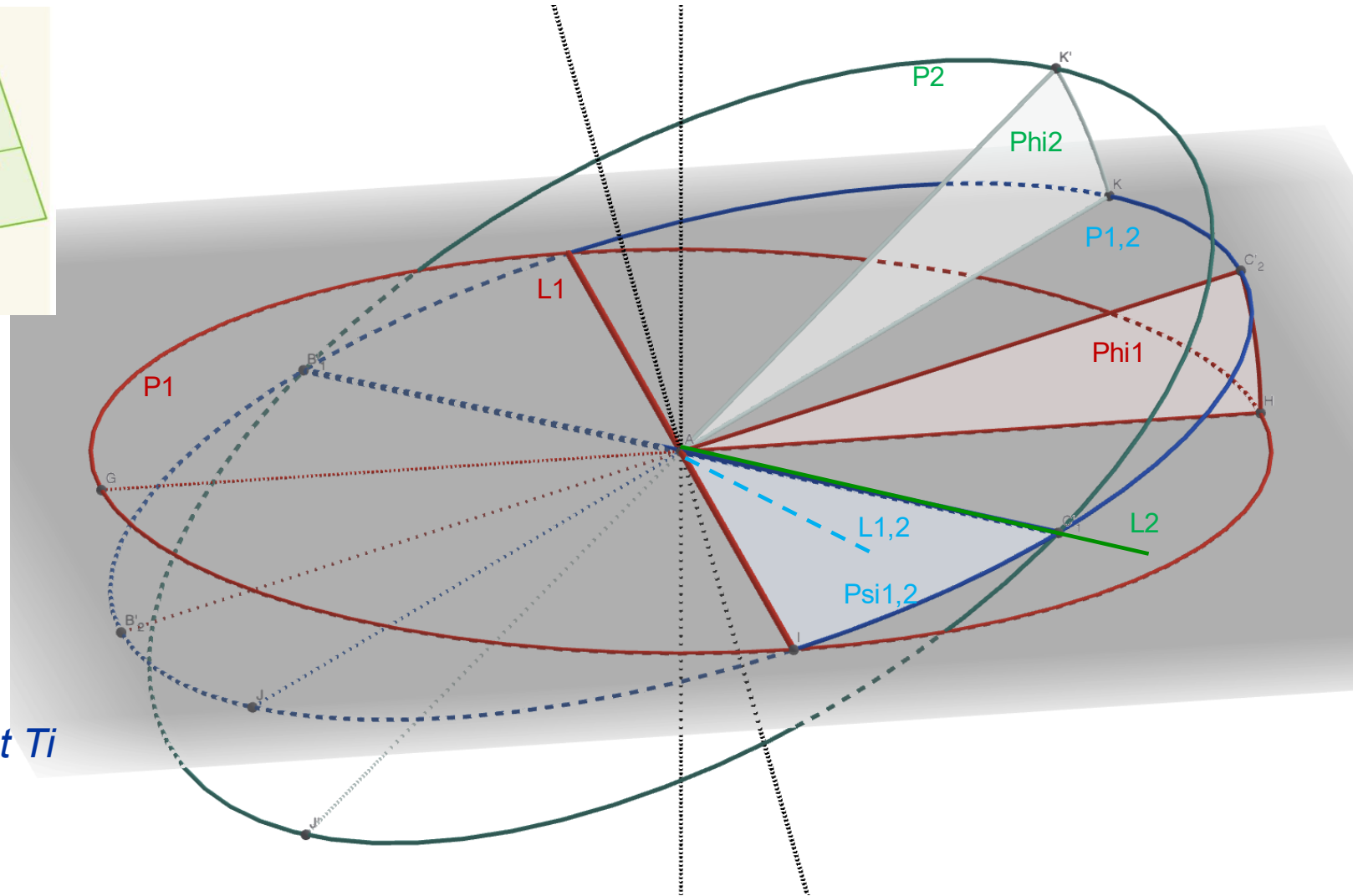
In the figure, **T1** and **T2**
are translated onto **T1,2**

Actually, and this is a great asset: *each angle is considered around their correct T_i*

Phi1 around **T1**

Psi1,2 around **T1,2**

Phi2 around **T2**



Comparing with classical yaw / pitch / roll angles

ST 0601.8 UAS Datalink Local Set

MISB MOTION IMAGERY STANDARDS BOARD	MISB ST 0601.8
STANDARD	23 October 2014
UAS Datalink Local Set	

Aka “Tait-Bryant” angles of type $z - y' - x''$

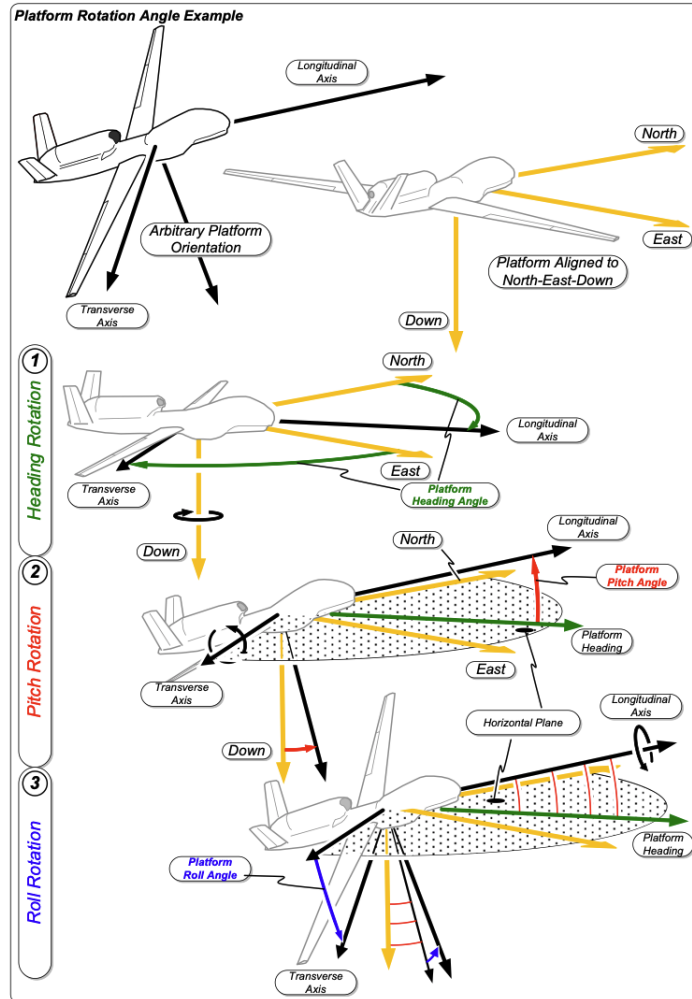
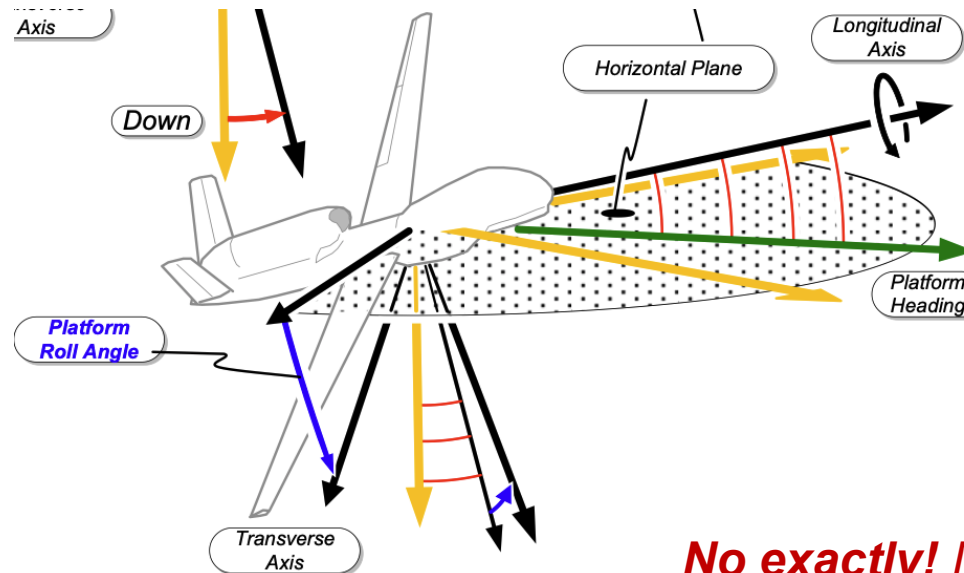
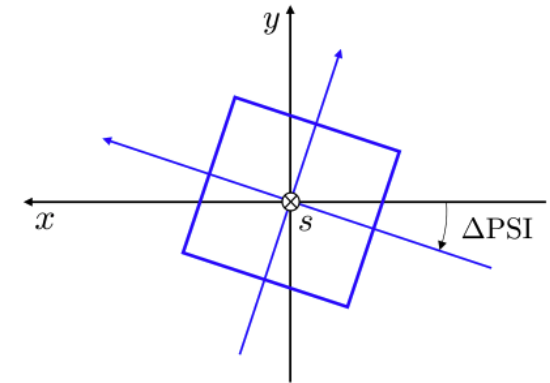


Figure 7-1 : Platform Rotation Angle Example

Focus on the roll angle



Is it the same as PSI?

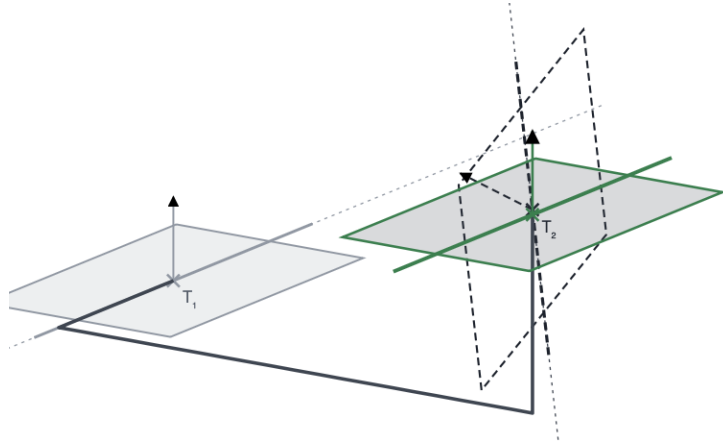


No exactly! Not defined around the same axis

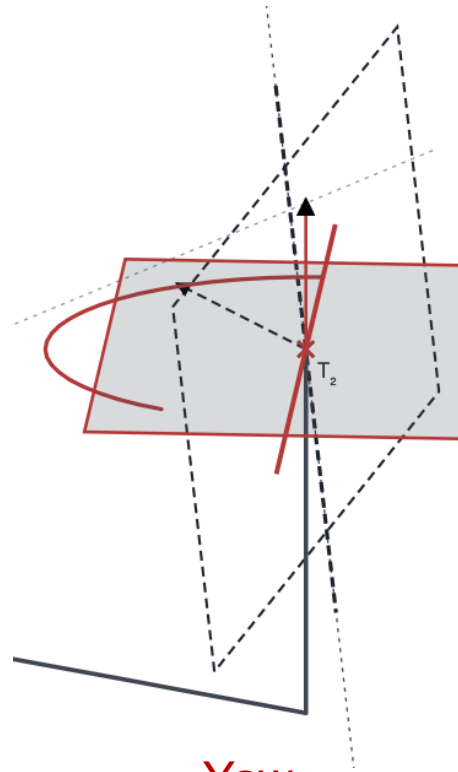
Depending on the choice of the (most of the time not explicit) convention, the roll angle can differ.
This adds up to the **uncertainty of specification**

Classical yaw / pitch / roll angles

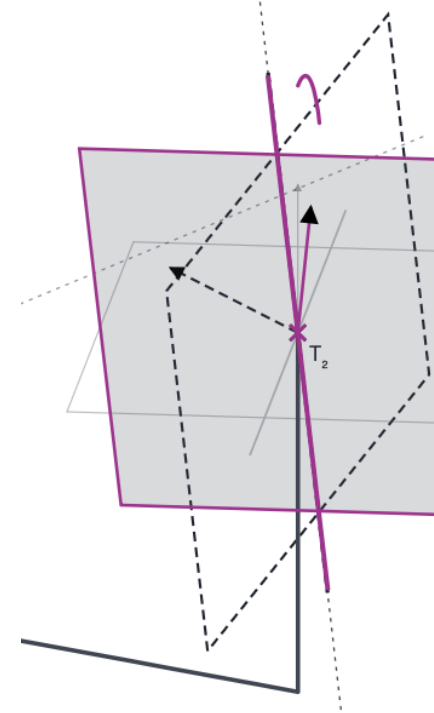
Tait-Bryan transformation steps applied to a ToLiP



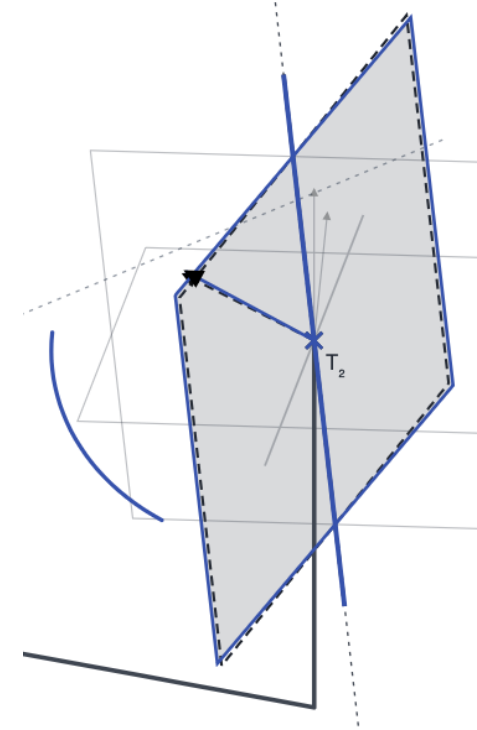
Three translations
along directions
perpendicular 2 by 2



Yaw
(in P1)



Pitch
(around a line
perpendicular to L2)



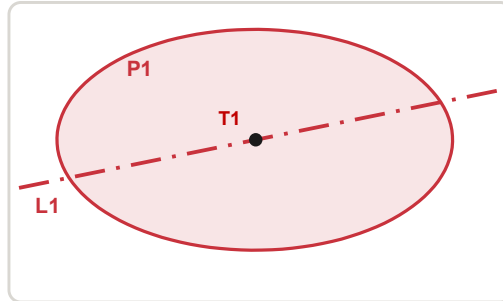
Roll
(around L3)

Comparison of “yaw / pitch / roll” vs CoToLiPian angles

yaw / pitch / roll

0. Initial state

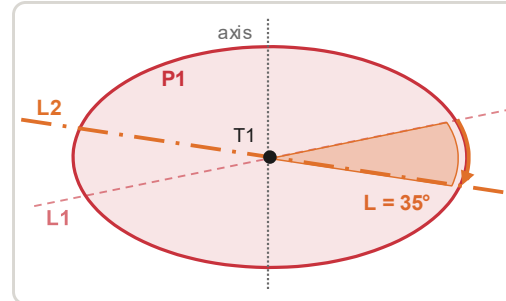
T1 L1 P1



Tait–Bryan z-y'-x'' sequence {L; LP; P} around T1

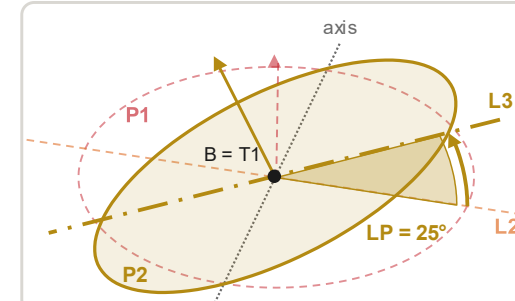
1. Rotation of type “L”

axis $\perp$ P1 at B $\rightarrow$ T1 L2 P1



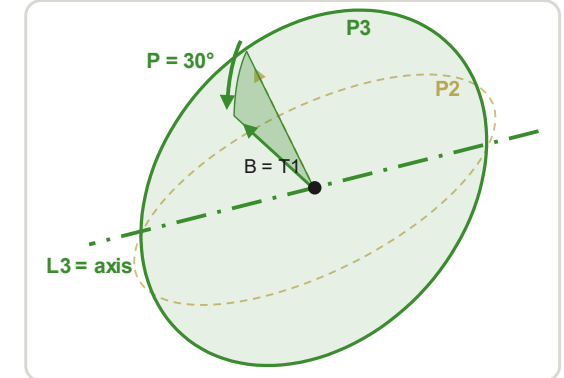
2. Rotation of type “LP”

axis $\perp$ L2 in P1 $\rightarrow$ T1 L3 P2



3. Rotation of type “P”

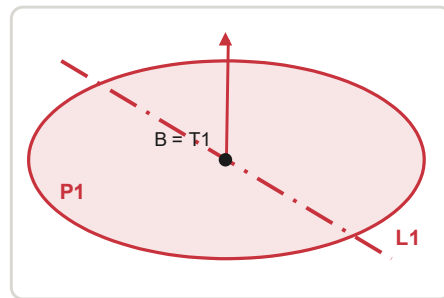
axis L3 $\rightarrow$ T1 L3 P3



*From the **red ToLiP** to the **green ToLiP**, by two equivalent routes (only angles considered)*

0. Initial state

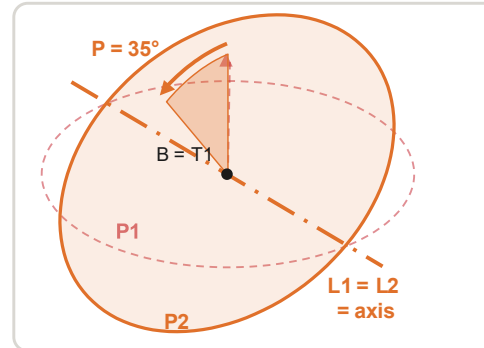
ToLiP1: T1 L1 P1



CoToLiP sequence {P; L; P} around T1

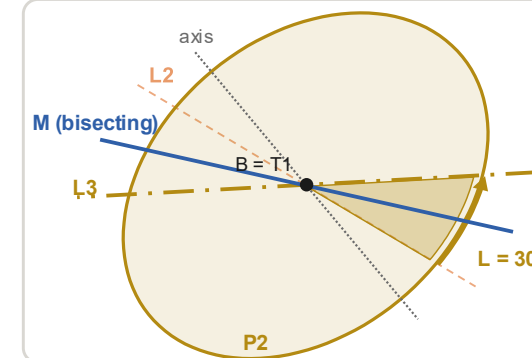
1. Rotation of type “P”

axis L1 = L2 $\rightarrow$ T1 L2 P2



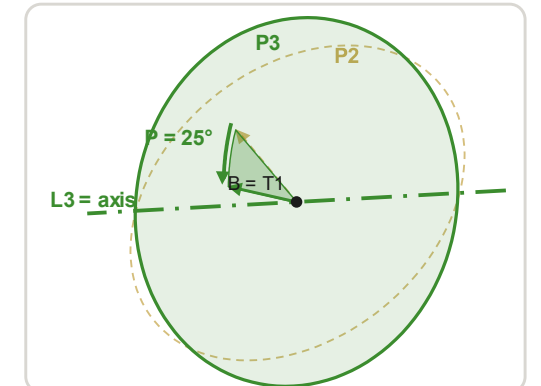
2. Rotation of type “L”

axis $\perp$ P2 at B $\rightarrow$ T1 L3 P2



3. Rotation of type “P”

axis L3 $\rightarrow$ T1 L3 P3



CoToLiP

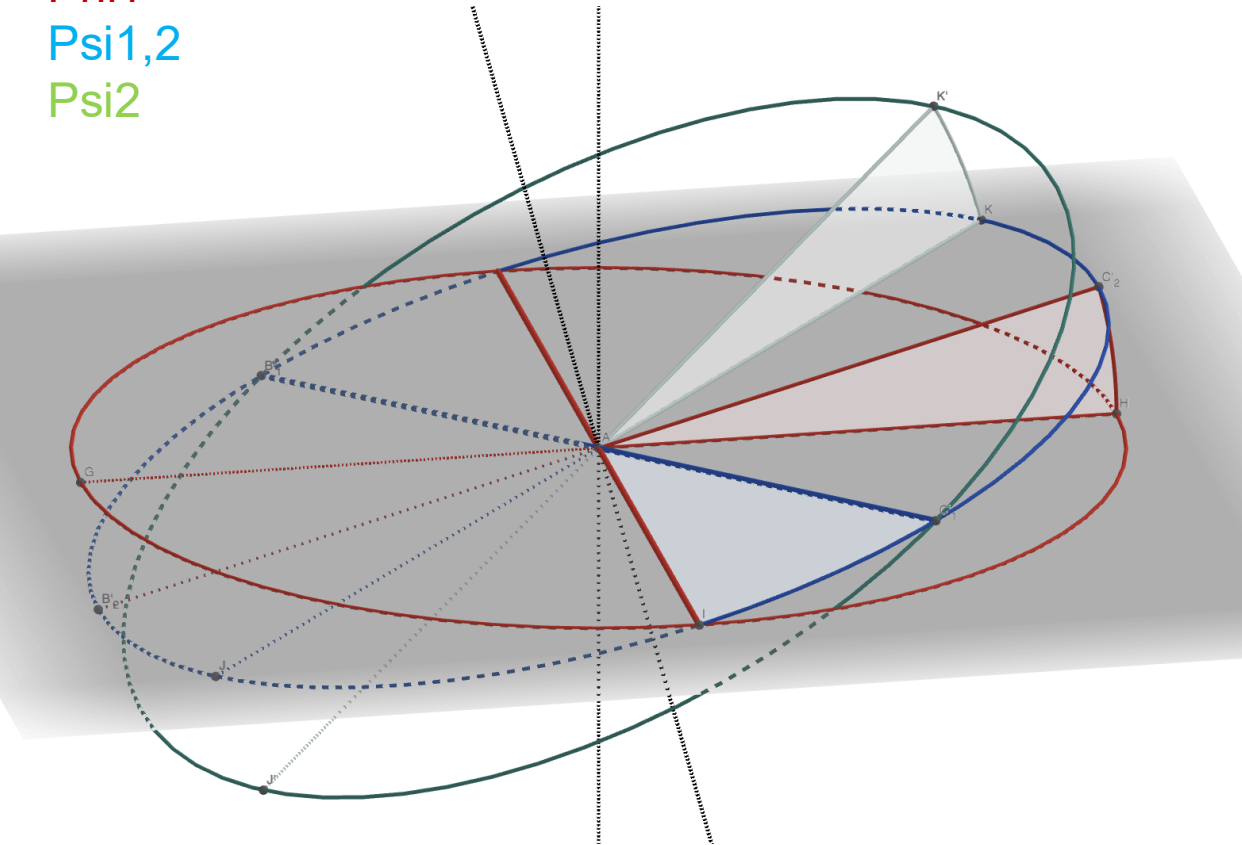
Different routes yielding to the same ToLiP transformation

CoToLiPian angles

Phi1

Psi1,2

Psi2

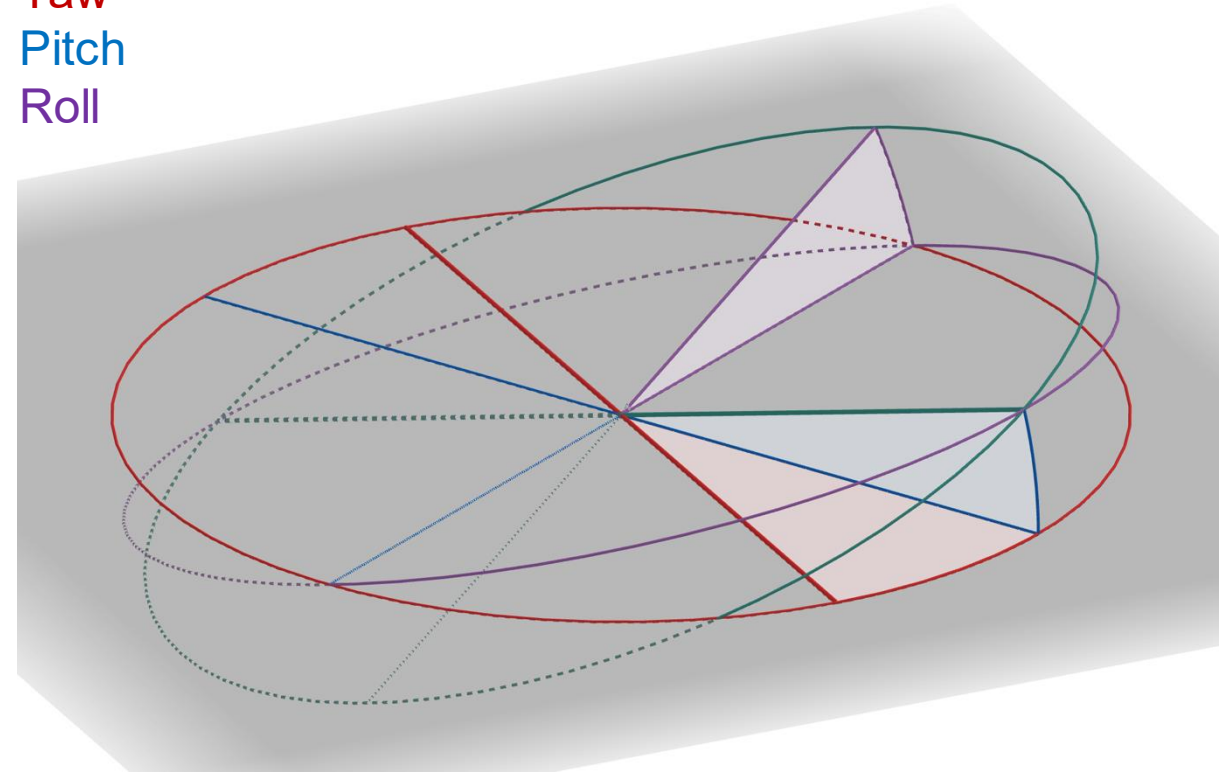


Yaw pitch roll angles

Yaw

Pitch

Roll



In most cases, discrepancy between the two routes is $< 10^{-11}$

The CoToLiP, a convention for mutual situation parameters?

Aim (for ISO/NWI 25431)

*Standardize the CoToLiP and its mutual situation parameters as a **default** operator*

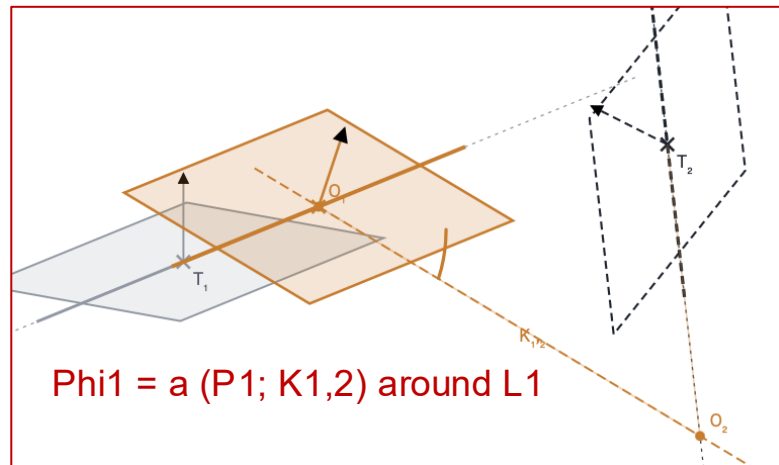
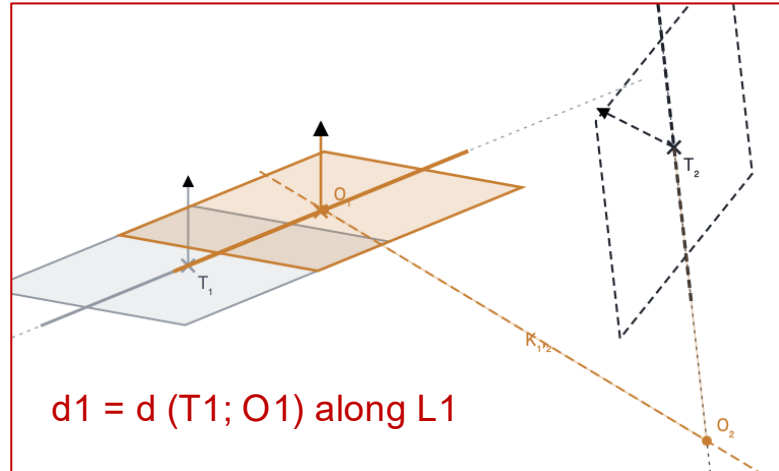
It will always be possible to define explicitly *other* operators

Advantages

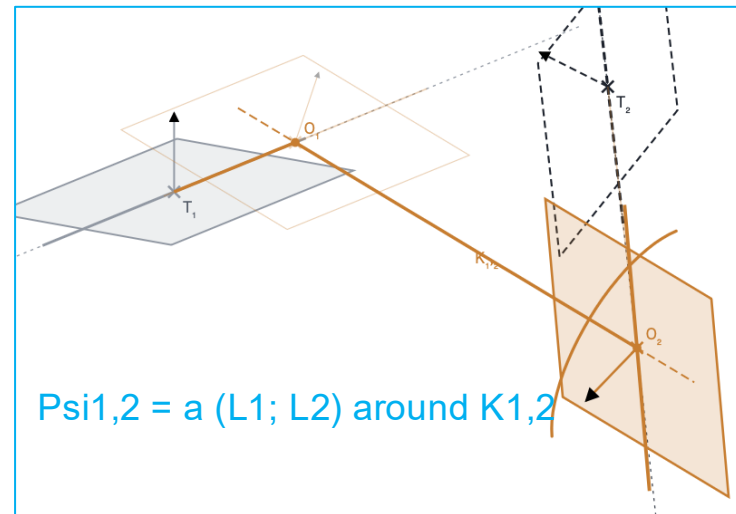
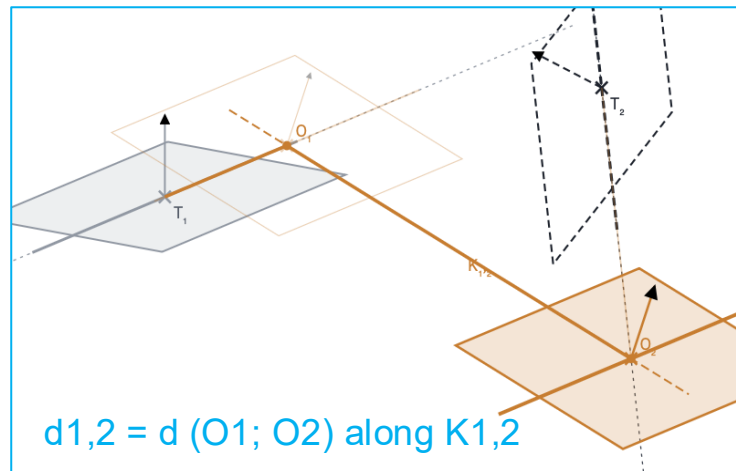
- CoToLiP is **symmetrical**
- The cotolipian parameters can be **signed** (*absolute* mutual situation) or **unsigned** (*relative* mutual situation)
- CoToLiP is a **commutative** operator: $\text{CoToLiP}(\text{ToLiP1}, \text{ToLiP2}) = \text{CoToLiP}(\text{ToLiP2}, \text{ToLiP1})$
- The angular parameters do not depend on the order of the sequence of rotations
- The parameters are grouped into three “motors*”.

*A *motor* (in projective algebra) is a combination of a translation and a rotation with the same axis

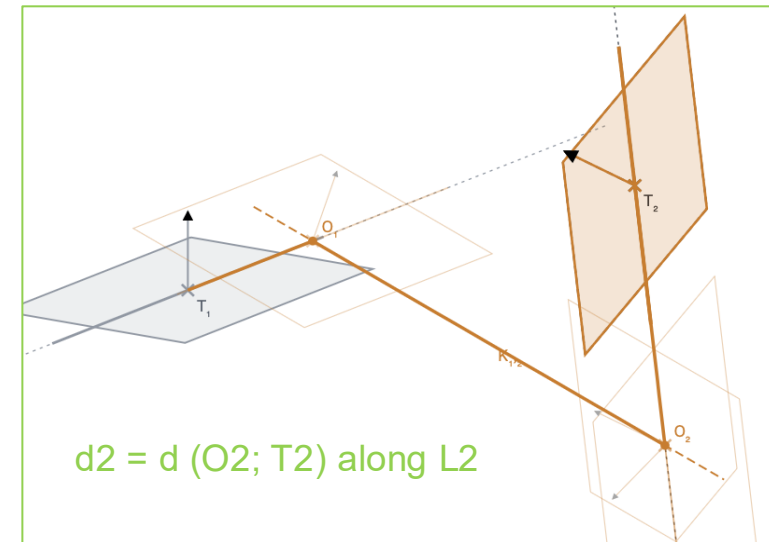
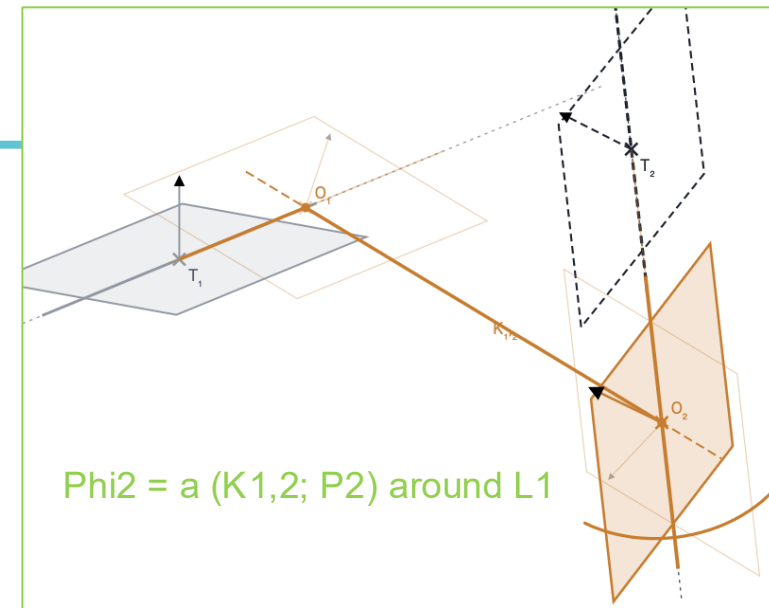
CoToLiPian “motors”



First “motor”



Second “motor”



Third “motor”

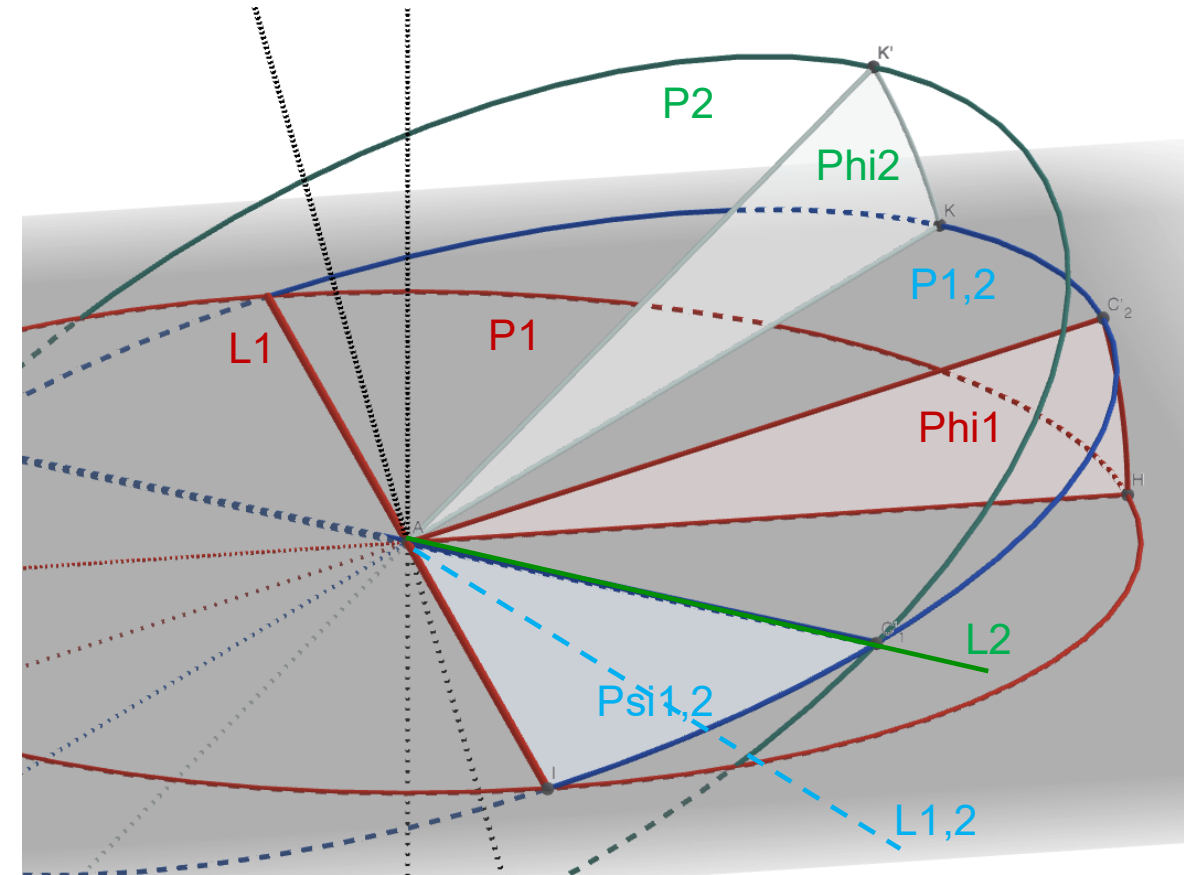
Determining a CoToLiP from real data (1/2)

Input before characterisation by a CoToLiP:

1. **ToLiP1**, the nominal situation of ToLiP
2. A set of measured points on the feature 2* whose situation is represented by the yet non-established ToLiP2

Operations: *: operations not represented

1. *From the set of measured points, establish **ToLiP2** by an association (e.g. with Spatial Analyser)
2. *Establish the common perpendicular **K1,2** between **L1** and **L2**, and determine the distances **d1**, **d2**, and **d1,2**
3. In the figure, **T1** and **T2** are translated onto **T1,2**
4. Angle (**L1**, **L2**) -> **Psi1,2**, the bisecting line is **L1,2**
5. The plane containing **L1** and **L2** is **P1,2**
6. Project the perpendicular to **L1** in **P1,2** onto **P1** -> **Phi1**
7. Project the perpendicular to **L2** in **P1,2** onto **P2** -> **Phi2**



Output:

- $\{T1,2; L1,2; P1,2\} = \text{ToLiP1,2}$
- **d1**, **d2**, and **d1,2**
- **Phi1**, **Phi2** and **Psi1,2**

Absolute mutual situation parameters of ToLiP2 with respect to ToLiP1

How to specify situation characteristics

When

- *ToLiP1 (red) is the nominal ToLiP of the situation of our device,*
 - *ToLiP2 (green) is established from the measured data,*
- then CoToLiP 2,1 is our researched “CoCoToLiP”*

How to specify the limit conditions on the CoCoToLiP?

- Initial (traditional) track: *a table with $\pm n$ rms limit condition values: but how to deal with the implicit undefined or possibly inconsistent parameters?*
- First variant (IWAA 2022 and 2024, and MST paper): *proceed by analogy with existing ISO GPS tools on the axis of an associated cylinder, and define a tolerance zone;*
- Second variant (IWAA 2026): *direct tolerancing of mutual situation parameters – and actually, back to the first track, without the implicit!* 

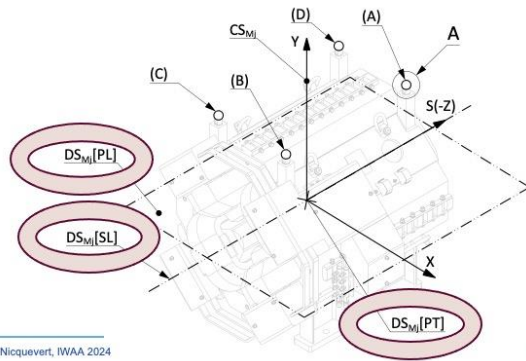
Situation specification of a situation feature, *first variant 1/2*

Explicit representation and indication of situation features



Representation and indication of situation features according to ISO/DIS 20223:2024

A complete ToLiP defines the situation of the surfaces upon which it is established



2024-10-10, B. Nicquevert, IWAA 2024

34

Idea: there are tools in ISO 1101 (or ASME Y14.5) to specify the orientation or position of the axis of an associated cylinder, or an associated plane or mid-plane of an associated biplane.
Ex. $\otimes$, $\odot$ and $\oplus$ modifiers (ISO 1101, 8.2.2.2)

What about *extending their use* to any type of situation feature? (once solved the issue of their extent, that is by default infinite)

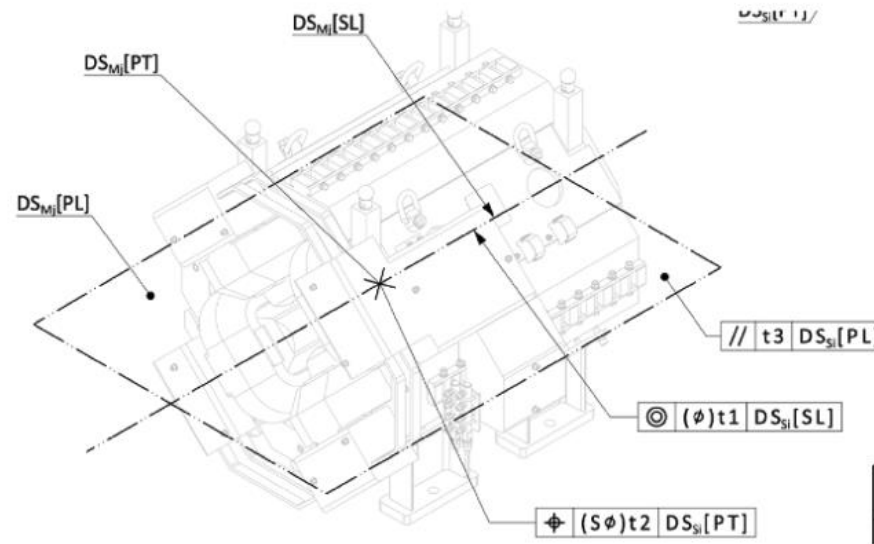
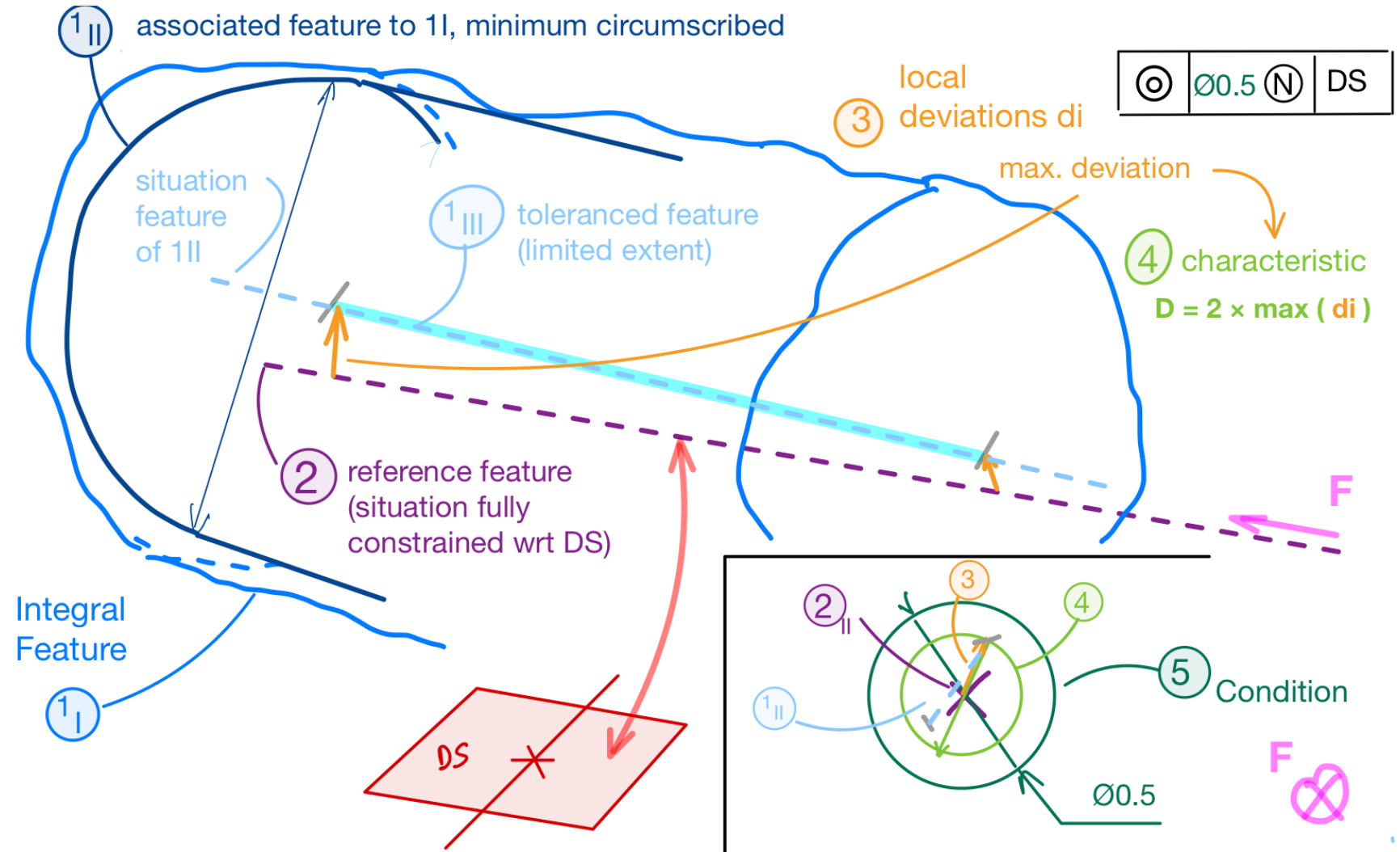


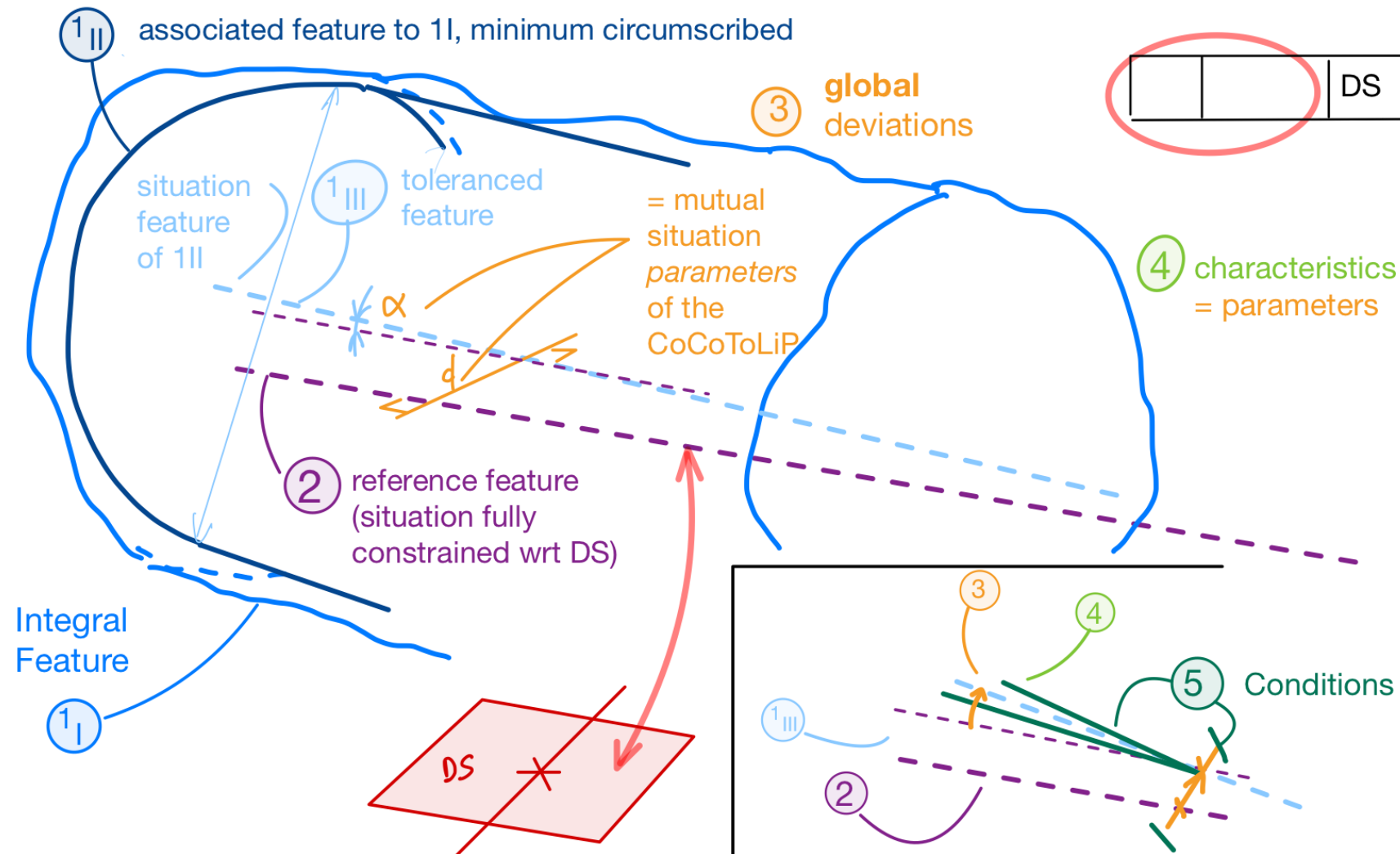
Figure 16. Geometrical specification of the location and orientation of the three situation features of the magnet M_j with respect to the situation features of the functional slot S_i . Excerpt of the drawing specifying the installation operation (see appendix C).

Situation specification of a situation feature, *first variant 2/2*

Exemplified here for the case of the truncated situation feature of an associated feature (minimum circumscribed) to a specified feature nominally cylindrical. The theoretically exact feature (the straight line 2) is constrained to be situated with respect to the datum system DS (situation not fully exemplified here, e.g. // DS[PL] at a given distance from DS[PT] in a direction defined by DS[SL])



Situation specification of a situation feature, *second* variant



Simpler and more direct way of tolerancing

Nota: the symbology is not yet standardized!
Follow the development of ISO/NWI 25341

This situation specification variant would assign an *explicit and univocal meaning* to our $\pm$ rms Tables

Nota: the “parameter specification element Q” defined in ISO 1101:2017, 8.2.2.3.2, may be used to refer to a 1 sigma value of the quadratic deviation

Comparison between the three variants, for a magnet “axis”

FUN (functional) specification

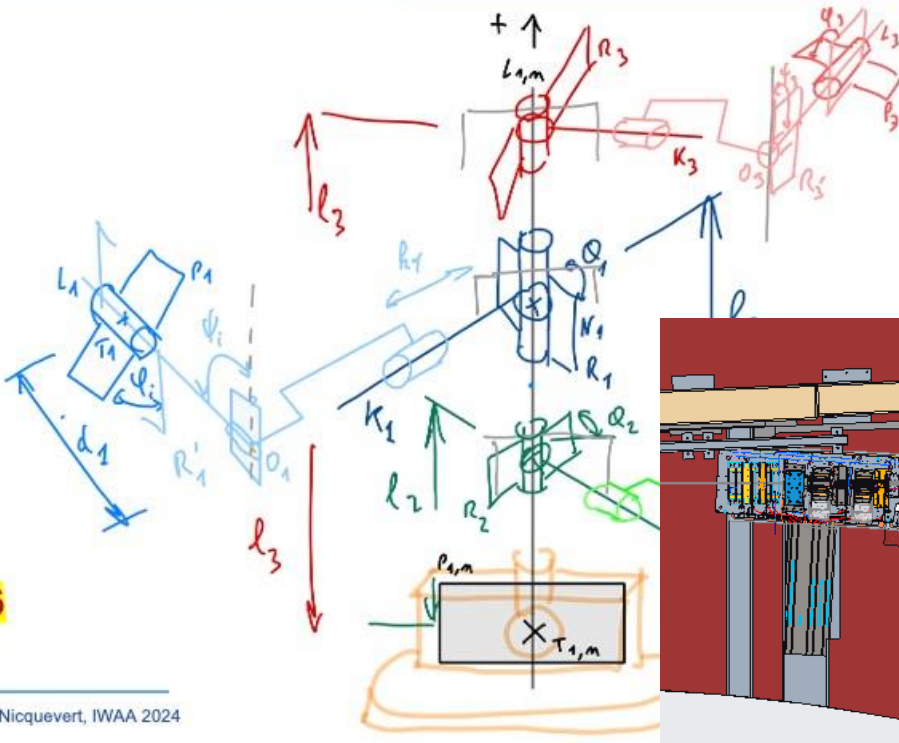
Step of the GPS^2 process	± rms Table	Variant “tolerance zone”	Variant “mutual situation parameters”
0. Nominal specified features	Implicitly, magnetic axis	Situation feature [SL] of the magnetic ToLiP	Situation feature [SL] of the magnetic ToLiP
1. Real specified features	Measured magnetic axis	[SL]1 associated to the measured magnetic axis, extent limited	[SL]1 associated to the measured magnetic axis
2. Associated feature	A straight line at the exact situation?	[SL]2 situated at theoretically exact situation	[SL]2 situated at theoretically exact situation
3. deviations 1 vs 2	?	Local deviations between the points of the two [SL]	Defines a global deviation and this is NEW
4. Characteristic on 3.	?	Doubled maximum deviation	Mutual situation parameters SL1 vs SL2
5. Limit condition on 4.	The values in the Table	A tolerance zone	The <i>adapted</i> values in the Table!

And the MuToLiP?

Perspective 1: MuToLiP: generalizing CoToLiP

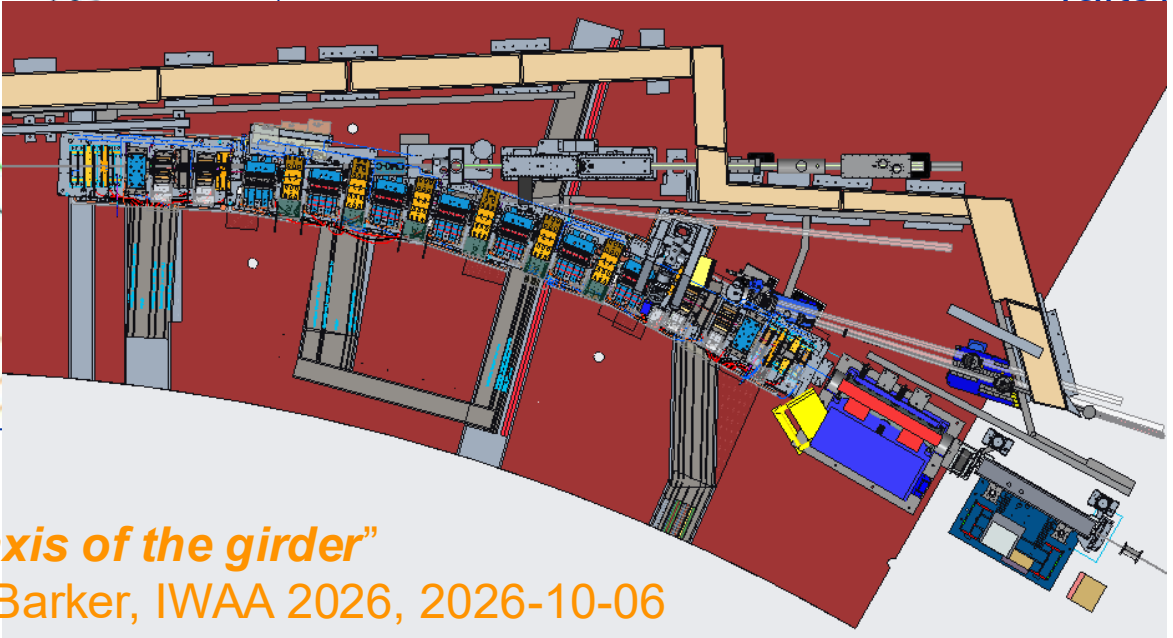
MuToLiP (multiple composition): operator for the parametrisation of the mutual situation of *any* number of ToLiPs, $n \geq 2$
Useful to establish the ToLiP of any **constellation** of spheres

For IWAA 2026



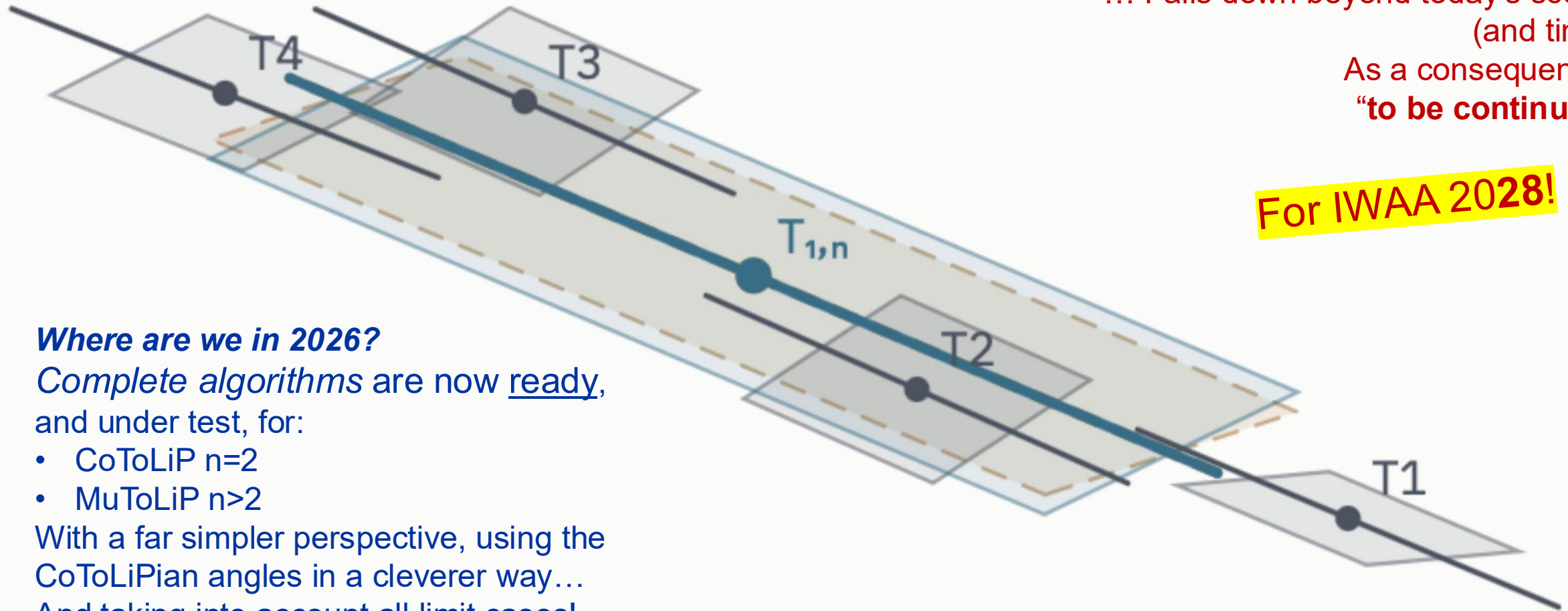
Provides a very convenient
“average” CoToLiP

Very useful for multiple devices when the “roll angle” is not uniquely defined (twin aperture magnets of FCC-ee) or not even functional (e.g. LBNL ALS-U rafts)



“Provide a physicist’s defined axis of the girder”
Jana Barker, IWAA 2026, 2026-10-06

CoToLiP and MuToLiP algorithms



... Falls down beyond today's scope
(and time)

As a consequence:
"to be continued"

For IWAA 2028!

Where are we in 2026?

Complete algorithms are now ready,
and under test, for:

- CoToLiP $n=2$
- MuToLiP $n>2$

With a far simpler perspective, using the
CoToLiPian angles in a cleverer way...
And taking into account all limit cases!

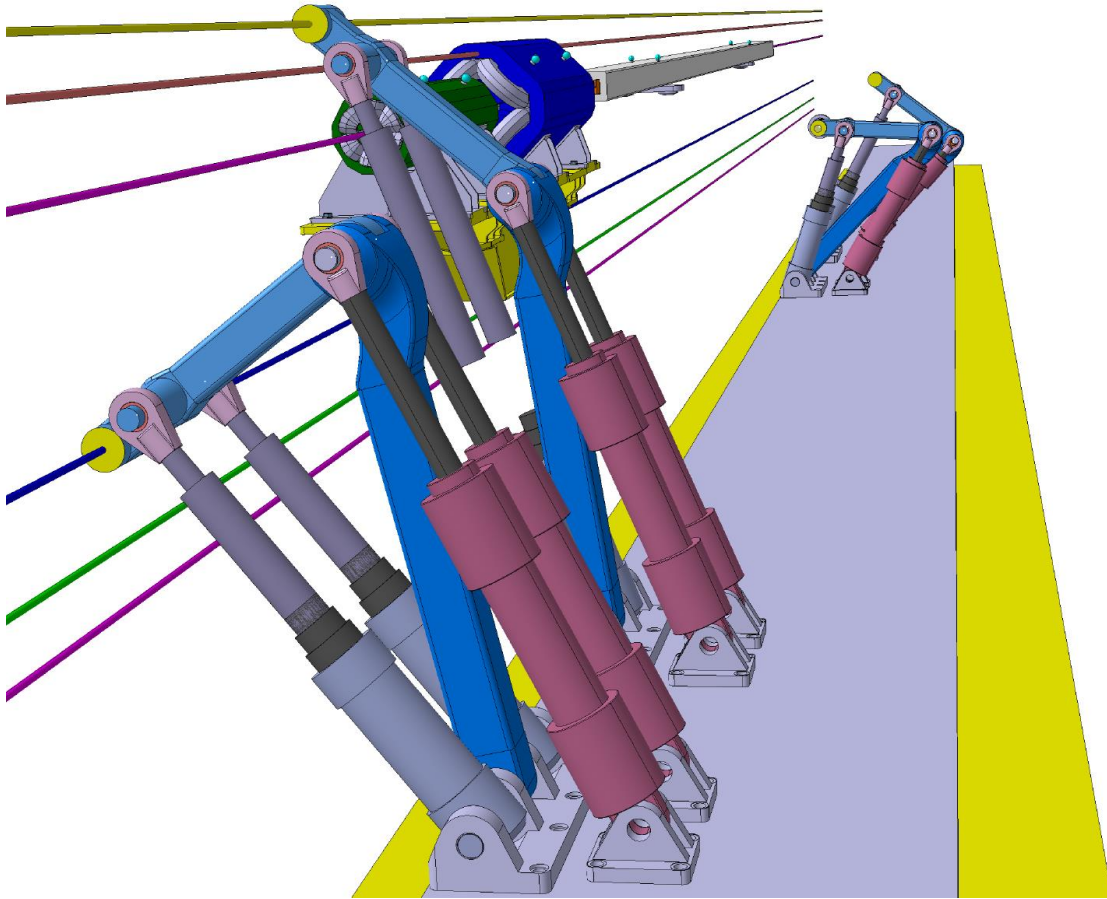
Other usages of CoToLiP: installation in the tunnel

Handling and unloading during installation is already a kind of first alignment!
Aiming at a submillimetric range of accuracy

From LHC transfer table (2003) ...

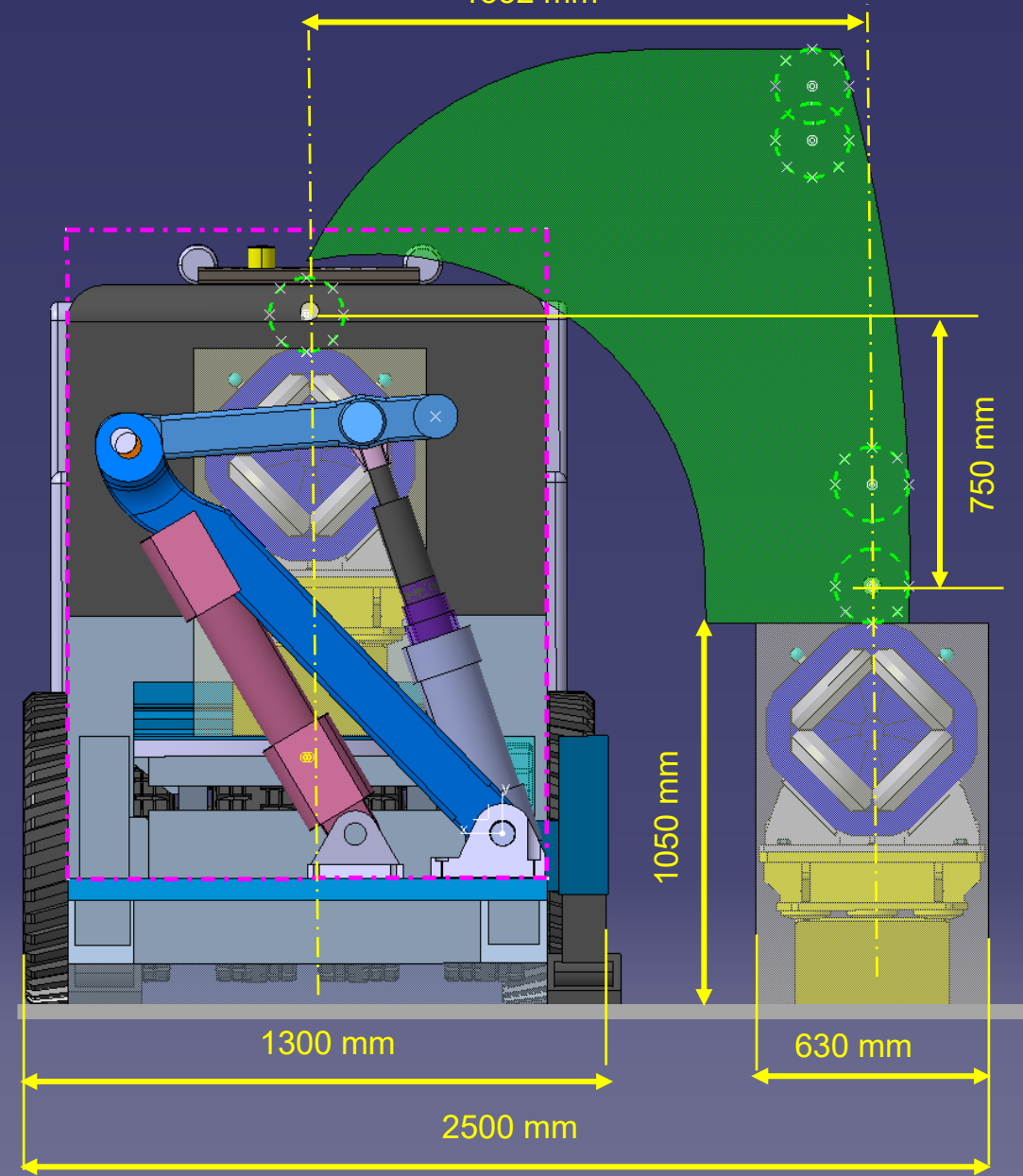


Toward the future



... to FCC automatised installation (2038?)

© courtesy G. Villiger, CERN EN/THE, June 2026
1532 mm



References

On top of the three IWAA presentations mentioned in the body of this presentation:

Nicquevert, B., Rey, F. “Handling the Functional Features of Accelerator Components Using ISO GPS Situation Features”. J. Phys.: Conf. Ser. 2687 072028 (2024). <https://doi:10.1088/1742-6596/2687/7/072028>

Nicquevert Bertrand, Rey Fabien. “Handling the Functional Features of Accelerator Components Using ISO GPS Situation Features.” In Proceedings of IPAC’23, Venice, Italy, 2023.
<https://inspirehep.net/files/393f09317f81cd244bdbf0ee18c1c29d>

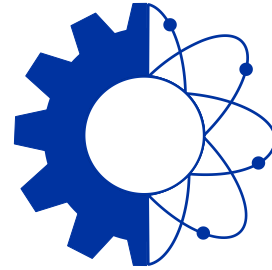
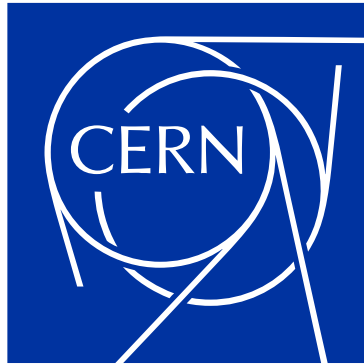
Qie, Y., Nicquevert, B., Anwer, N. “Functional specification of complex assemblies using projective geometric algebra”. *CIRP Annals*, vol. 73, 1, pp. 105-108 (2024). <https://doi.org/10.1016/j.cirp.2024.04.059>

Nicquevert Bertrand, “For a Global Process to Set a Geometrical Product Specification [GPS²]: a R&D Roadmap Toward an Extensive and Extended Use of Situation features in ISO Geometrical Product Specification (GPS) Standards”, *ADM2024 International Conference*, Palermo, Italy, Sep 2024. Springer, pp. 488–495, 2025.
https://doi.org/10.1007/978-3-031-76597-1_51

ISO 20223:2026, Representation and identification of situation features

Acknowledgments

- **A special thank to my “sparring partner” Fabien Rey / ESS**, for numerous discussions on the development of the concepts presented in this talk, and for his key contribution to many illustrations
- Many thanks to **CERN**, in particular for J.-P. Burnet (CERN FCC studies), and to S. Atieh, I. Ruehl and D. Lafarge (CERN EN dept) to support my participation to IWAA
- Thanks to I. Garcia-Aguirrebeitia Sanchez (CERN TE/MSC) and G. Villiger (CERN EN/THE) for their contributions. A lot of working ahead, working on how to use CoToLiP for the design of the FCC-ee quadrupoles, their installation, and many coming new topics
- Thanks also to A. Bertarelli and T. Capelli (CERN EN/MME), and colleagues from ISO TC213 and in industry, for providing me cases to support the needs to still improve our ISO GPS standards
- And many thanks to H  l  ne, Dirk and many others (CERN BE/GM) to open the door for new perspectives in dealing with the « geodetic common framework » to be used at multiscale levels.



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