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

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Session « Tools and Monitoring II »

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CoToLiP: where does it come from

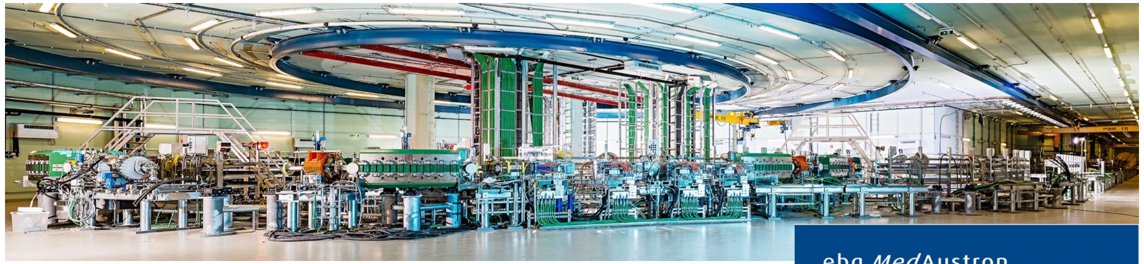
At **CERN** since 1992

CERN

CERN

ATLAS EXPERIMENT

1994 – 2004



ebg *Med*Austron

2009 – 2012

ess

2020 – 2022 (and beyond)

In special leave at LBNL since 2023

BERKELEY LAB

ALS-U ADVANCED LIGHT SOURCE

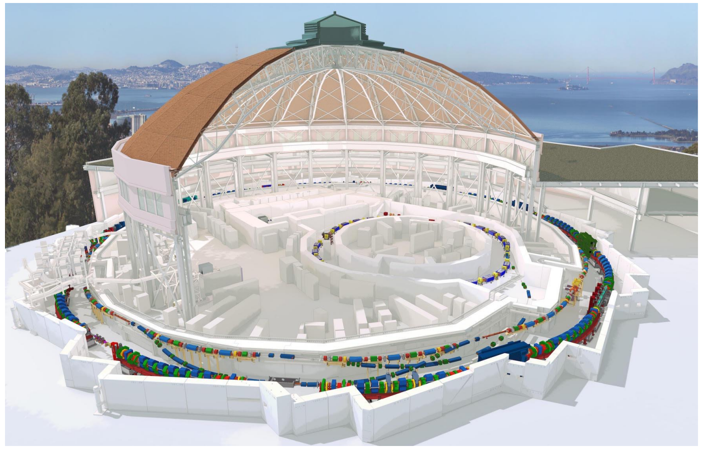
Expert since 2013

ISO

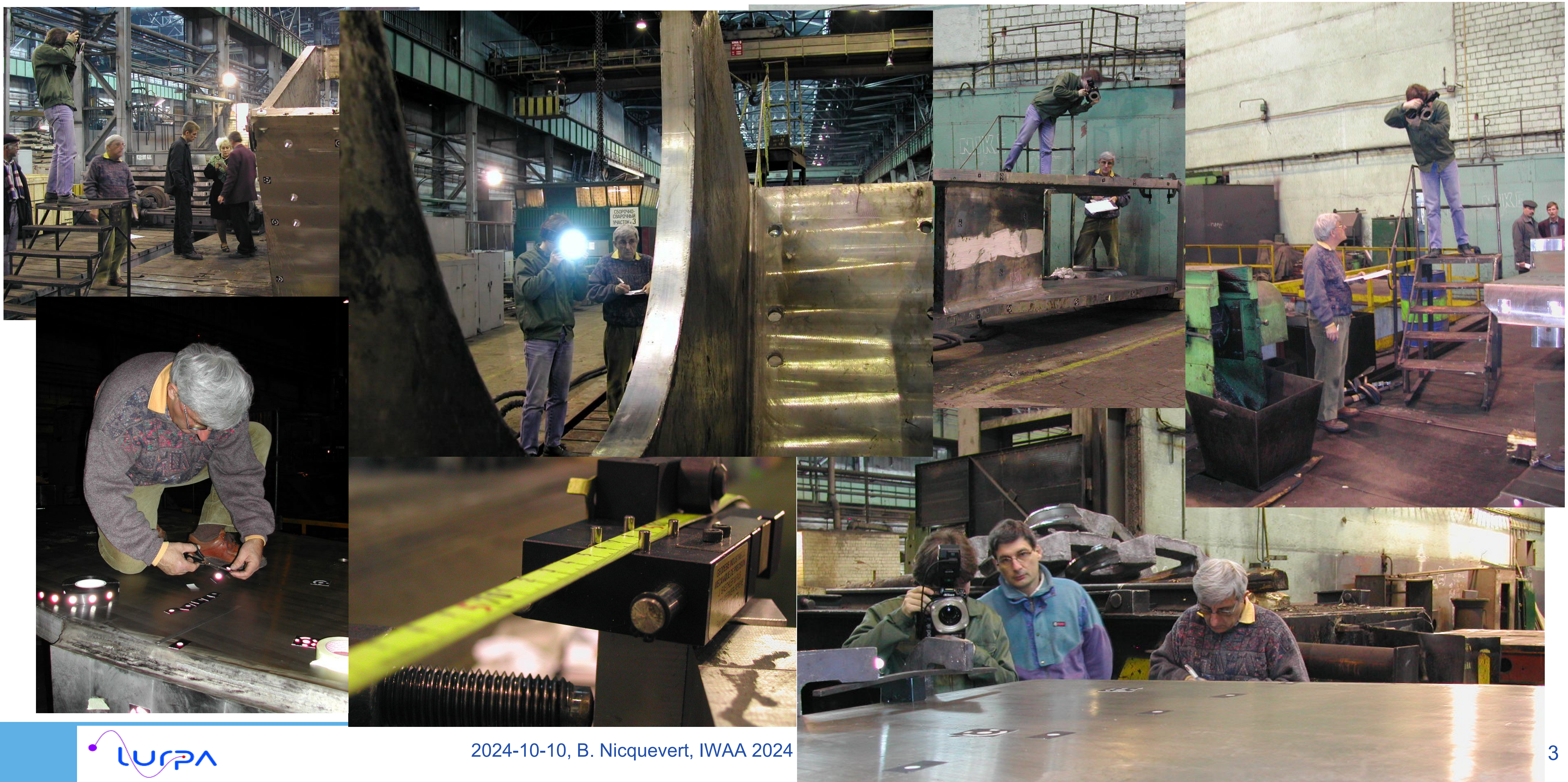
TECHNICAL COMMITTEES

ISO/TC 213

Dimensional and geometrical product specifications and verification

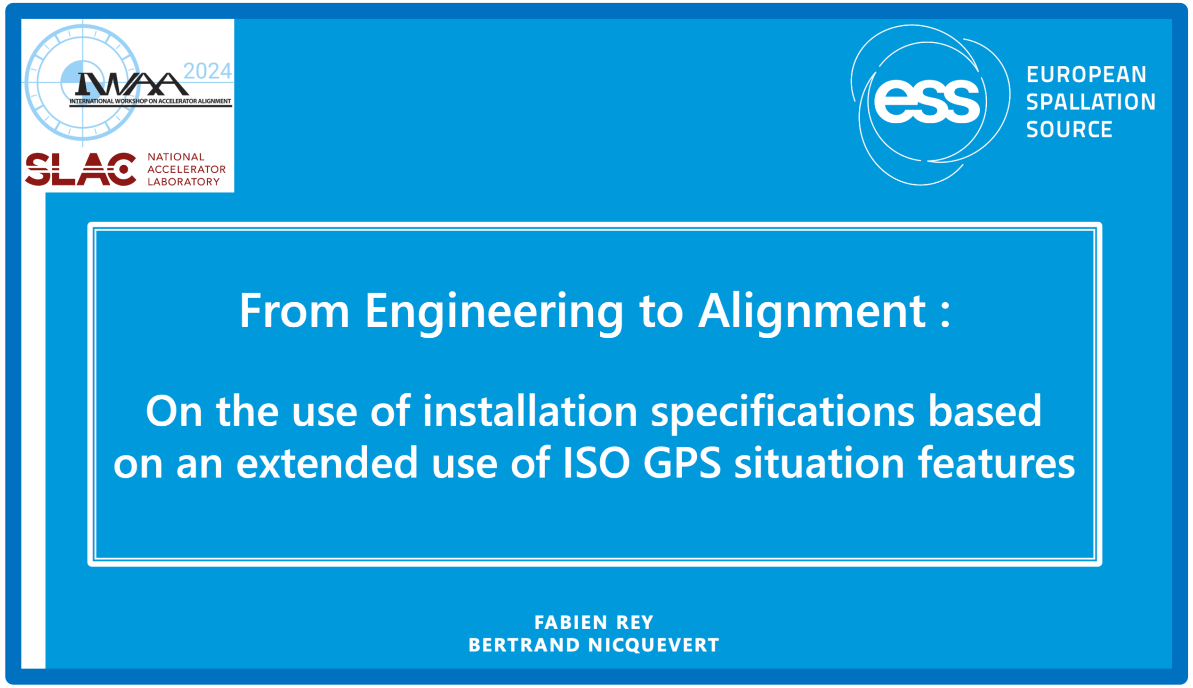


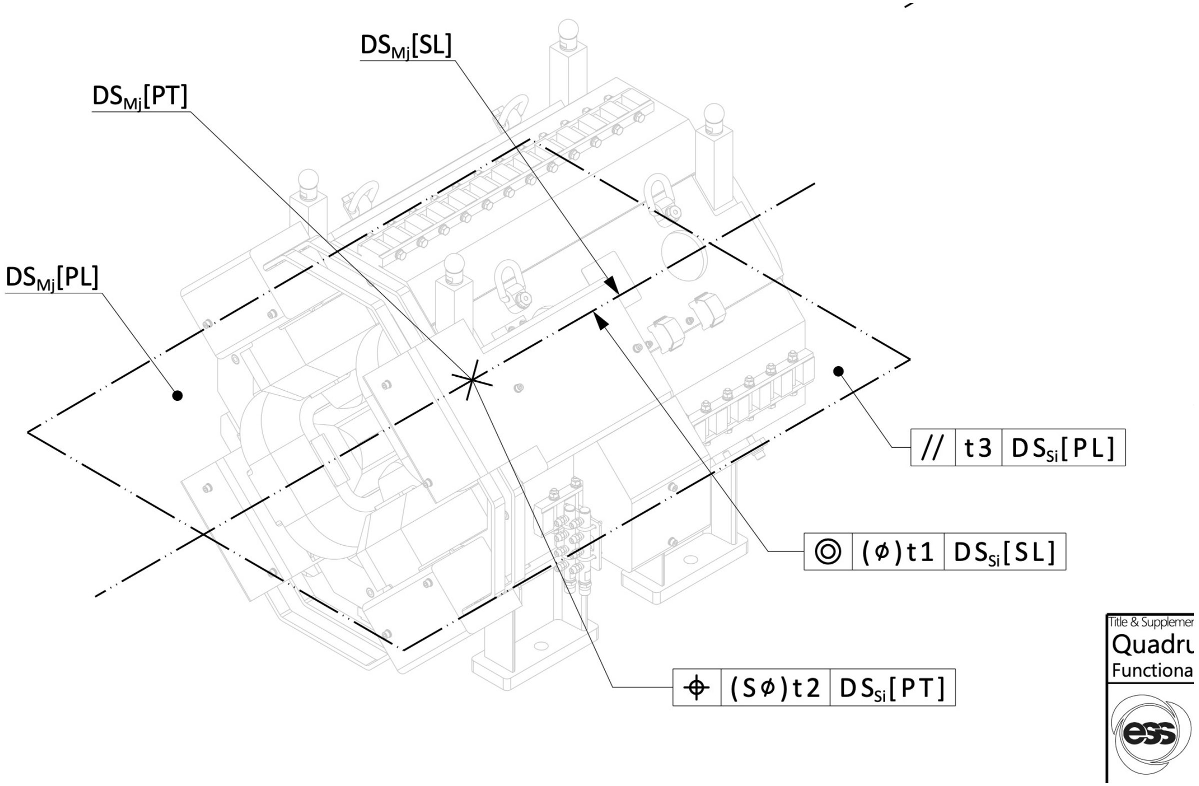
Start point: photogrammetry of ATLAS feet in Russia in 2002



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):





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

*** Live interruption ***

A quite interesting case!

… This also a follow-up on yesterday's Peter Manwiller's insightful talk!

More specifically:

- Typical of the cognitive gap between the functional and the verification perspectives
- And on the diversity of mindsets of the various communities

Question 6

A component needs to be fiducialized by probing mechanical features with a portable CMM as shown in Figure 3. A central axis is defined by connecting two measured circle centers—one measured at the upstream end and one at the downstream end. The component's top-plane is also measured. The central axis of the component is desired to be placed on a horizontal beamline to define the component's yaw and pitch orientation. The top-plane's normal vector is desired to be pointing up to define the component's roll. The measured angle between the top-plane normal vector and the central axis is 90.02 degrees.

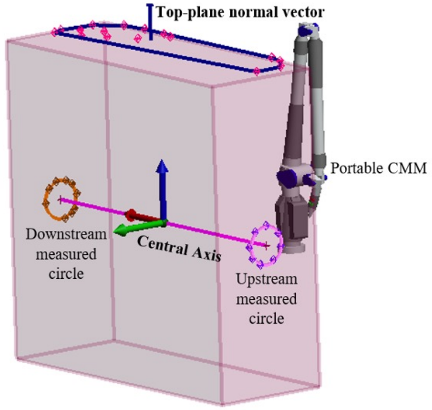


Figure 3: Magnet Fiducialization Measurements

Using the fiducialization data, how should the ideal placement be determined?

A) The top-plane's normal vector should be held as the primary axis, and the central axis should be the secondary axis. The third axis follows the right-hand rule.
B) The central axis should be held as the primary axis, and the top-plane's normal vector should be the secondary axis. The third axis follows the right-hand rule.
C) It doesn't matter whether the mid-plane or the central axis is held as primary.

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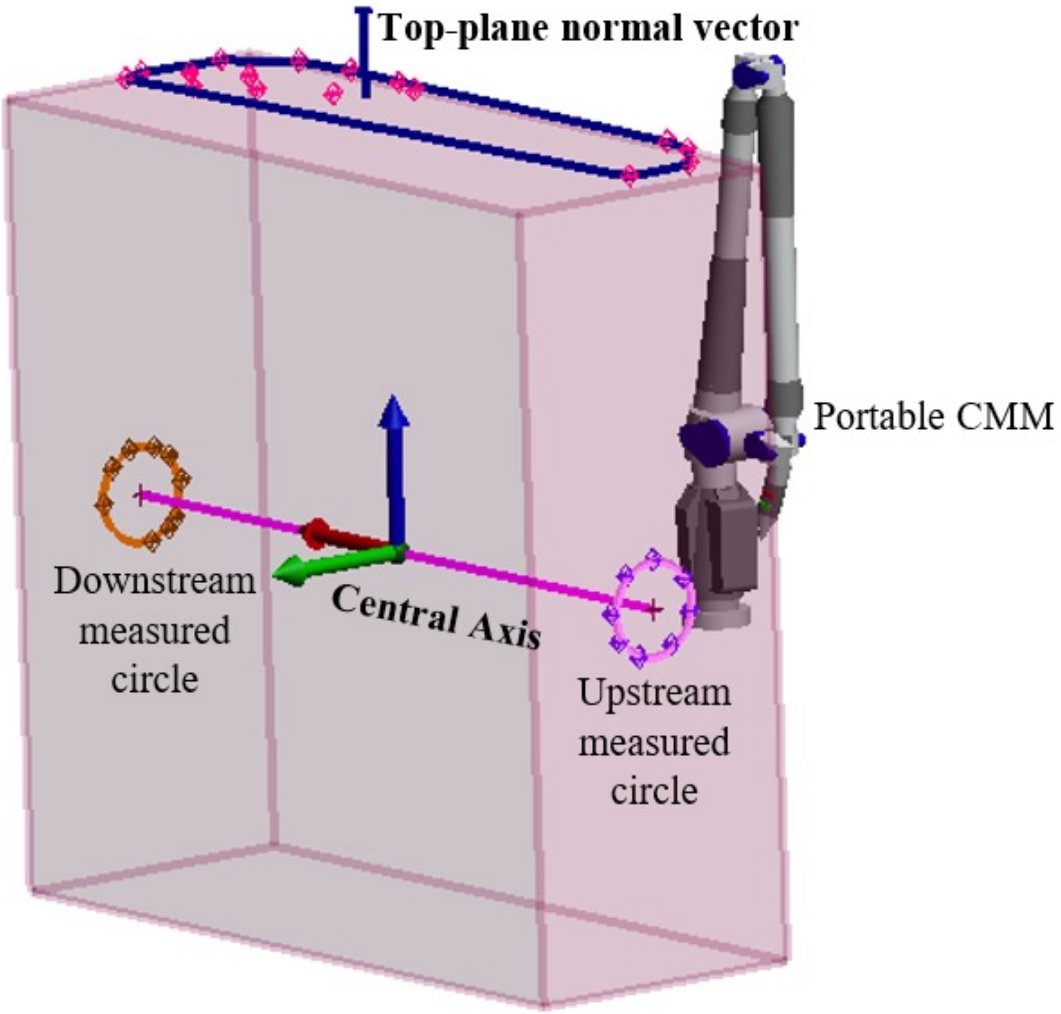
640 South Shaw Lane • East Lansing, MI 48824, USA
frib.msu.edu

A Survey of Accelerator Alignment Concepts for Professional Development, Slide 8

Good questions…

- Is B the correct answer? (top “plane” 1st)
- Or is it A? (“central axis” 1st)
- Or none of these?
- Actually I do not know
- And if I am the surveyor, I should prevent myself from looking for the answer, if this is not provided in the TPD (Technical Product Documentation = drawing or annotated 3D)
- **Because this extends *beyond* my scope and responsibility!**
- **What is FUNCTIONAL first**



ISO 8015:2011 principles

- □ Duality principle

5.10.2 Duality principle statement

The duality principle states that:

1) a GPS specification defines a GPS specification operator independent of any measurement procedure or measurement equipment, and;
2) the GPS specification operator is realized in a verification operator which is independent of the GPS specification itself, but is intended to mirror the GPS specification operator.

The GPS specification does not dictate which verification operators are acceptable. The acceptability of a verification operator is evaluated using the measurement uncertainty and any ambiguity of the specification.

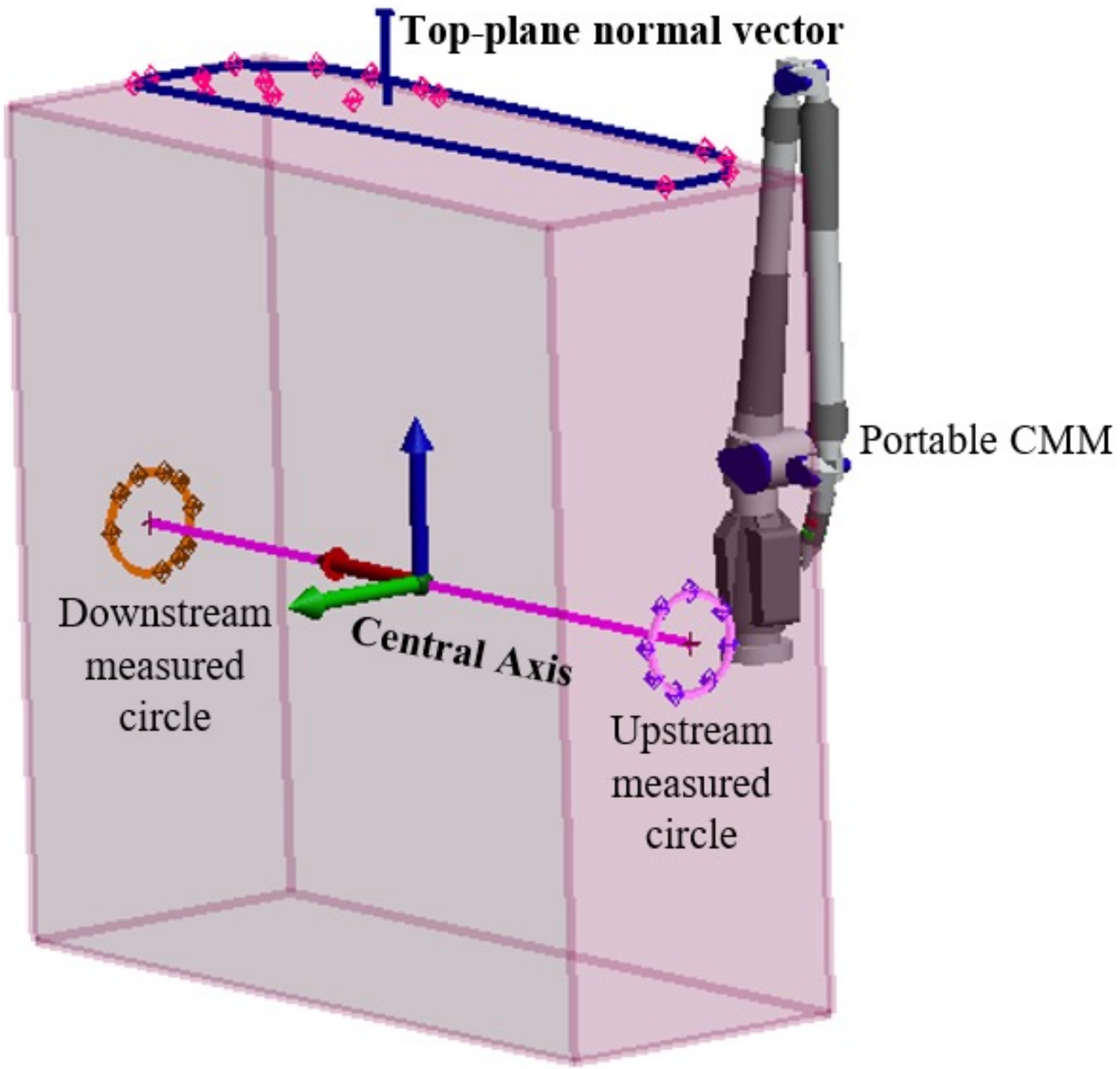
- □ Responsibility principle

5.13 Responsibility principle

Given the duality principle and the functional control principle, it is necessary to describe the closeness of a specification operator to the functional operator and the closeness of a verification operator to a specification operator. The ambiguity of the description of the function and the ambiguity of the specification together describe the closeness of the specification operator to the functional operator. These ambiguities are the responsibility of the designer. The measurement uncertainty quantifies the closeness of the verification operator to the specification operator. Unless otherwise stated, the measurement uncertainty is the responsibility of the party who is providing proof of conformance or non-conformance with a specification; see ISO 14253-1.

Beyond that, what is induced, guessed, implicitly interpreted?

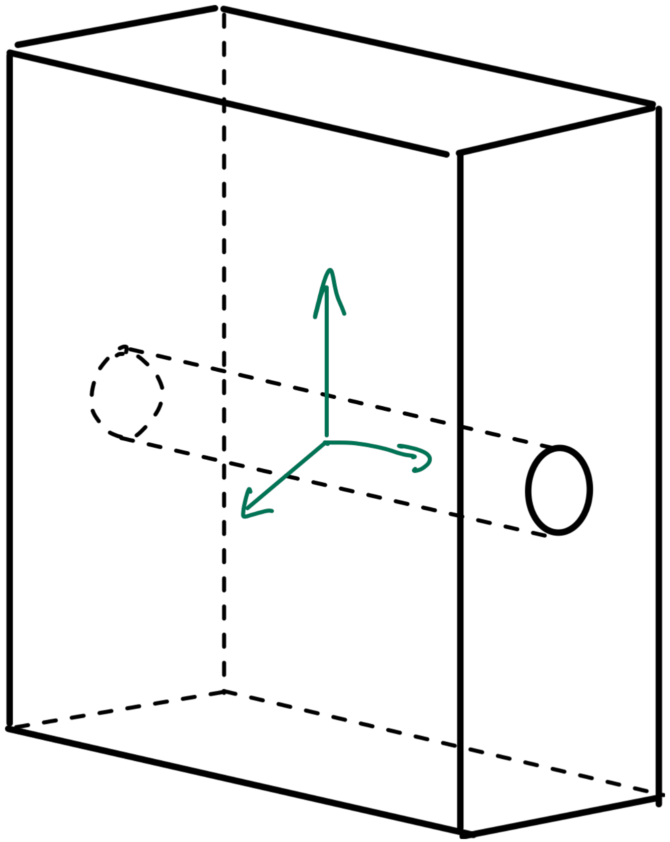
- (Fiducialization, really?)
- How do we get the "top-plane normal vector"?
- How do we get the "central axis"?
- Where do we measure the circles?
- How do I "orientate" the normal vector and the central axis?
- And first: how do I know I need to measure circles and the plane?
- And that I am looking for an "axis and plane" based coordinate system?
- And: the axis is axis of what?

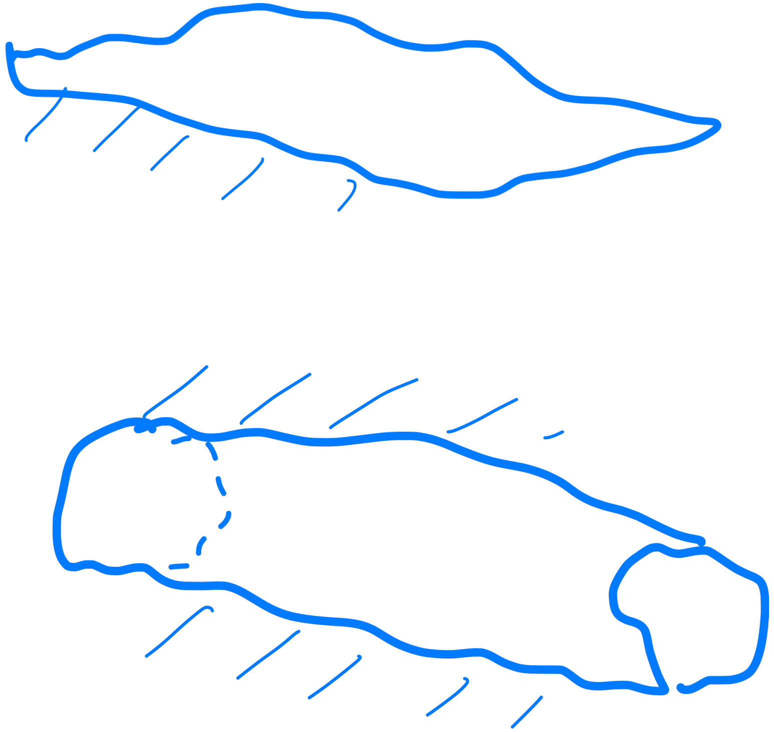


Etc etc etc…

What is available in our cases: points? A model?

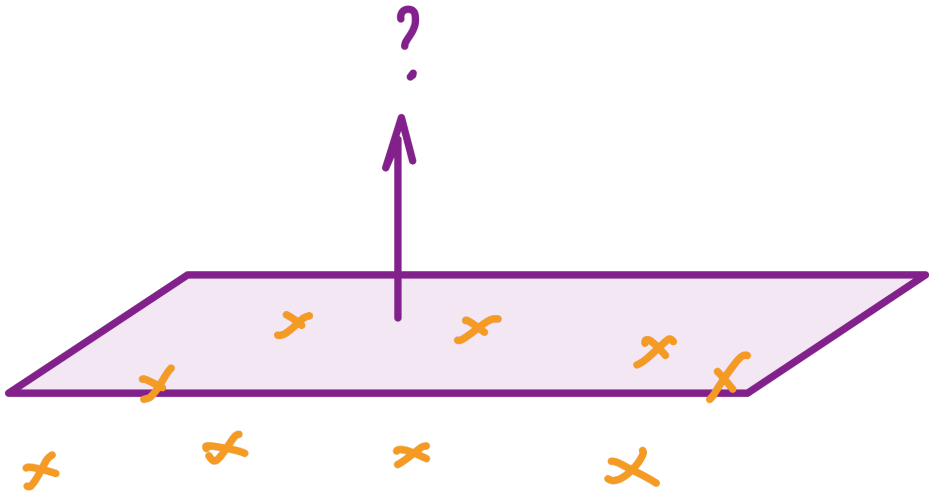
- □ Here follows a series of last minute hand-drawn slides to comment the case
- □ … and to (partially) attempt to make explicit the implicit (hidden) assumptions





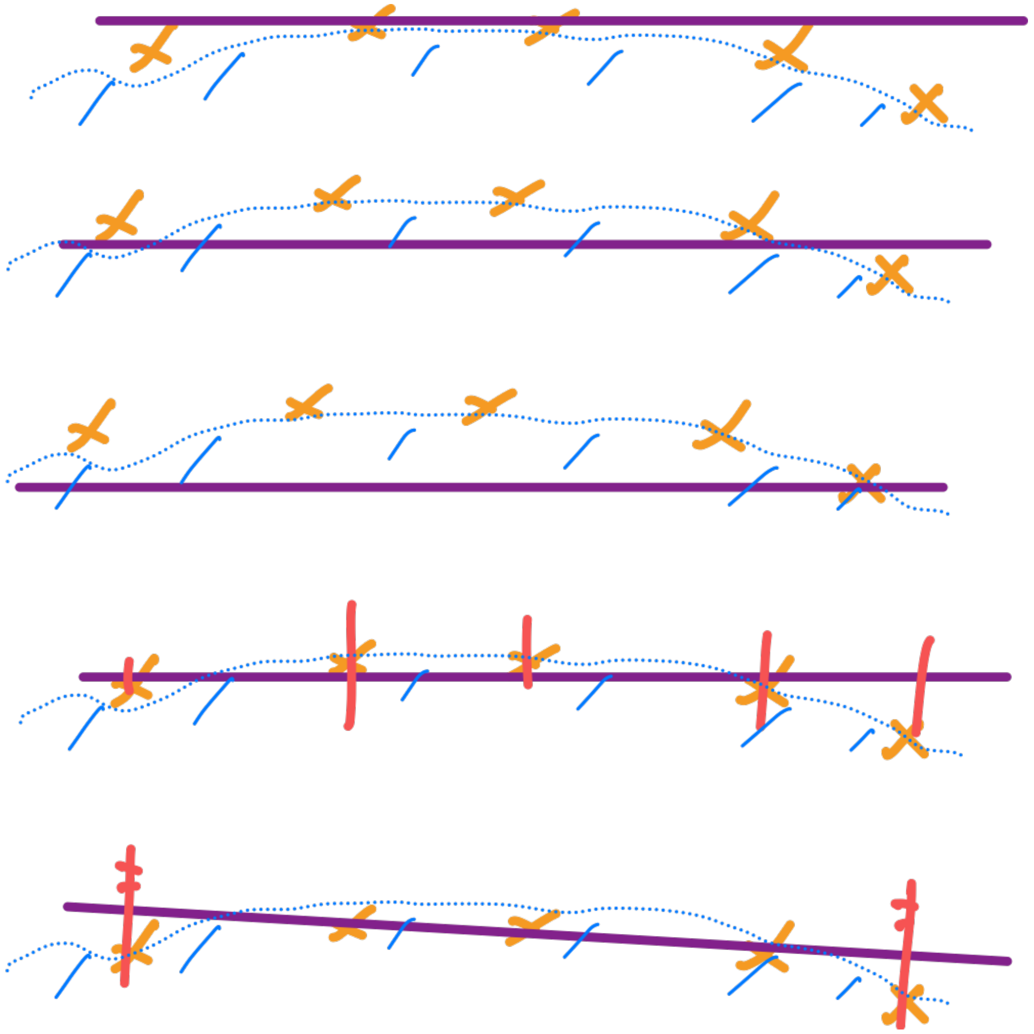
How to get the normal to the “plane”?

Using an associated plane?



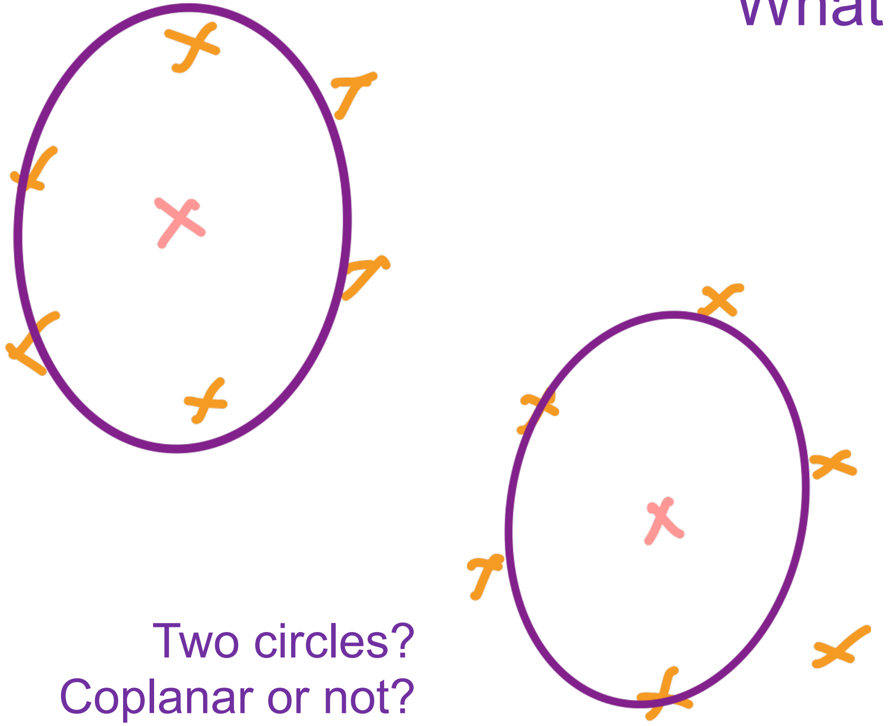
With which constraint with respect to material? Eternal, without, or internal?

And with which association criterion? Gaussian or minimax? Or…



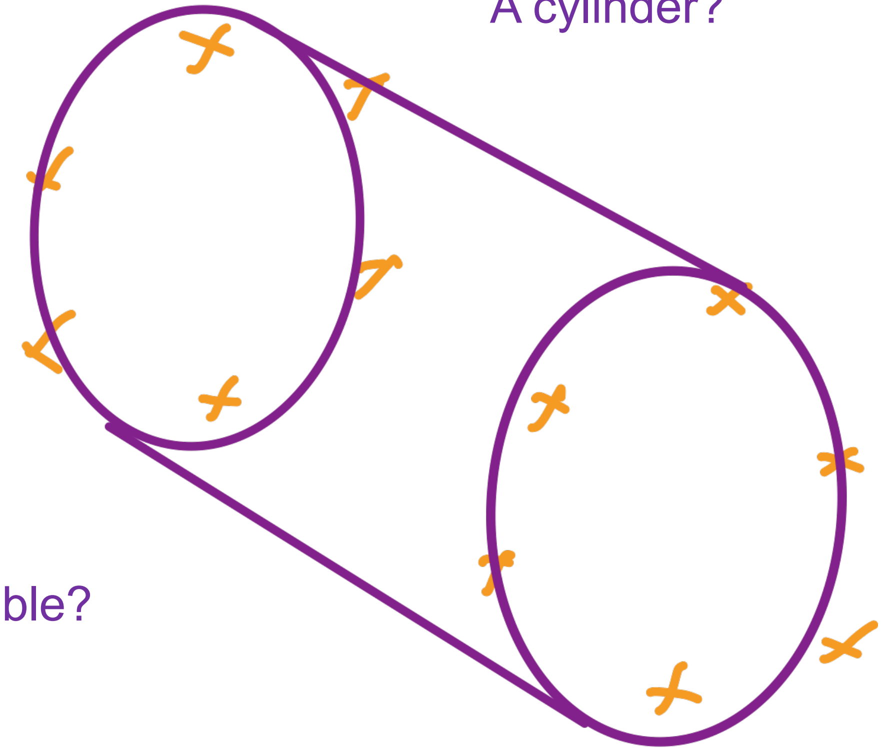
How to establish the “axis”?

What is the associated feature?



Two circles?
Coplanar or not?
Same or different size?

A cylinder?

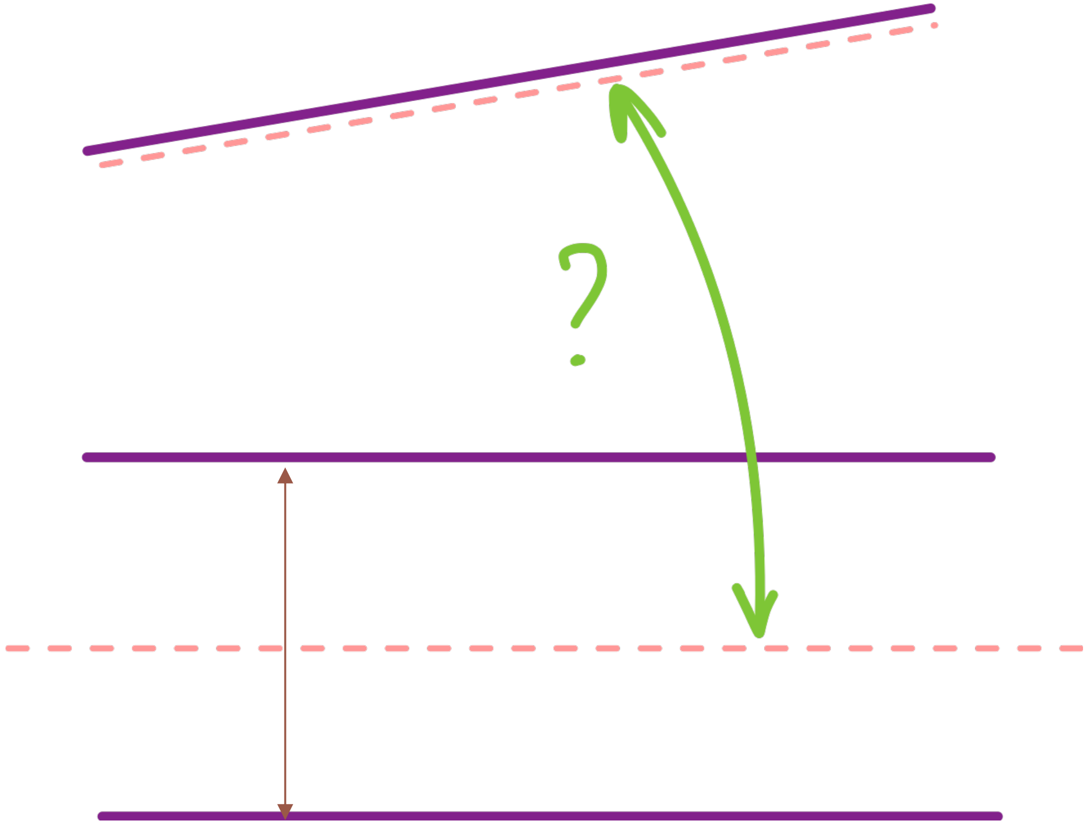


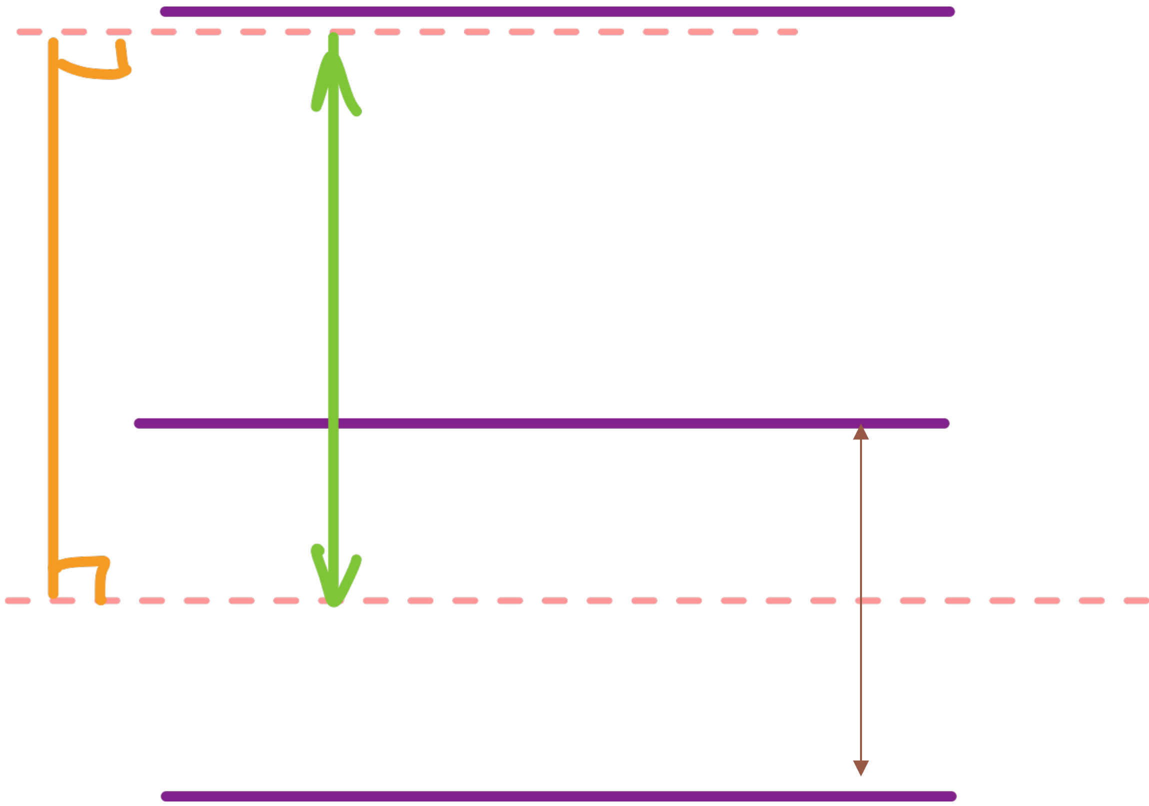
Size fixed or variable?

Or from magnetic measurement? (See our preprint paper)

Nicquevert and Rey. “Establishing and Situating Functional Features of a Machine Component Using ISO GPS Situation Features. Application to the Alignment of Magne in a Particle Accelerator”

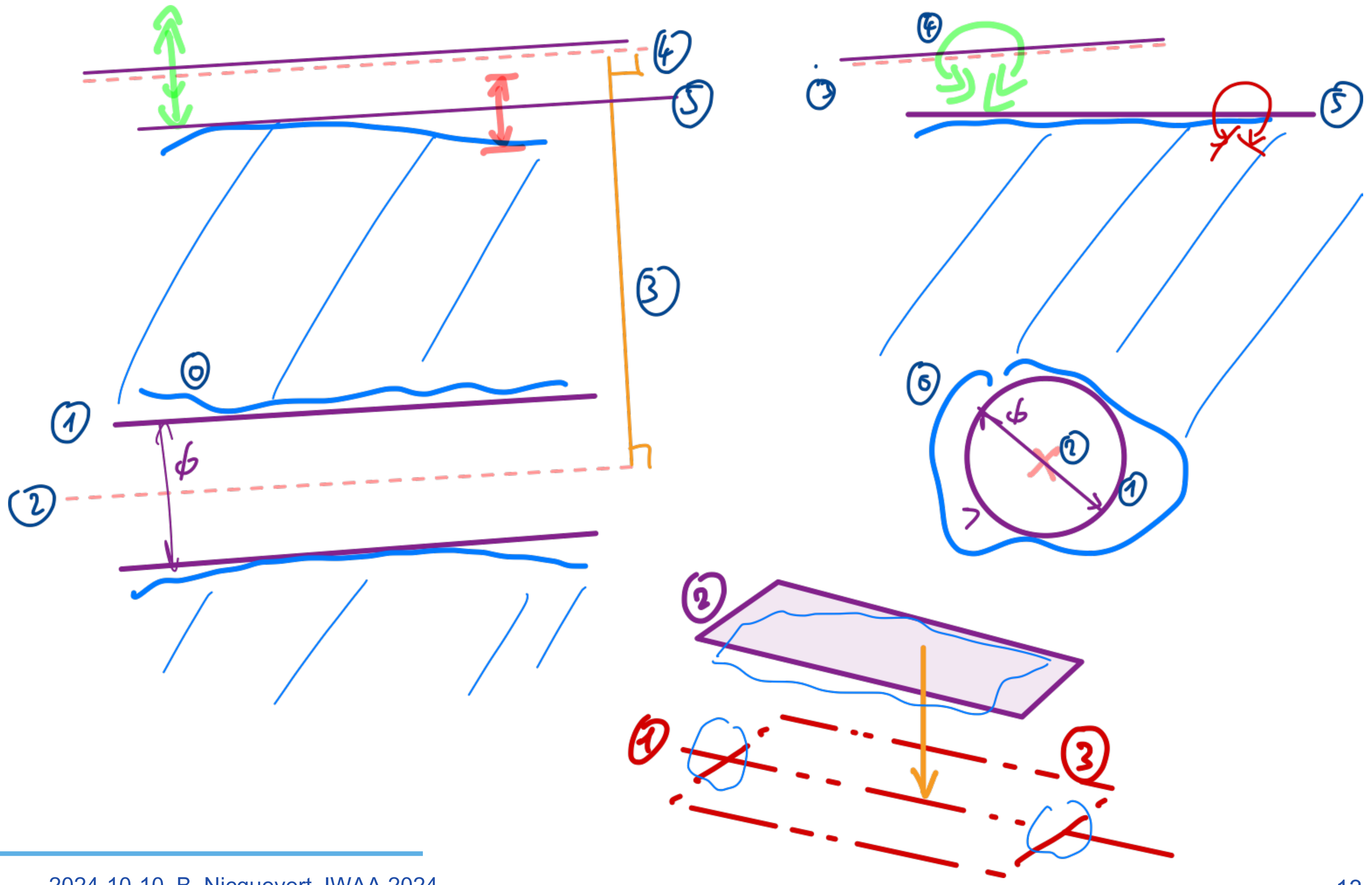
How to orientate the "plane" and the "axis"?



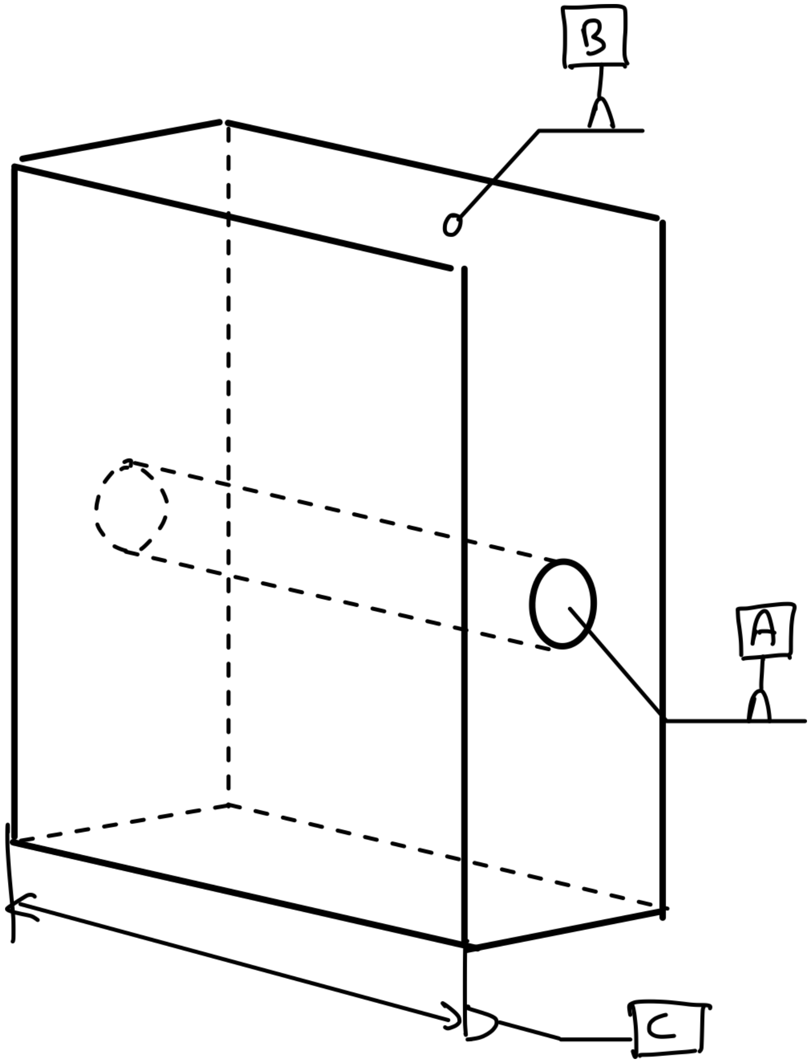


In which order the establishment of plane and axis?

First possibility A: starting with the axis



How to indicate it in the drawing? ISO 5459:2024 (Oct 4th…)

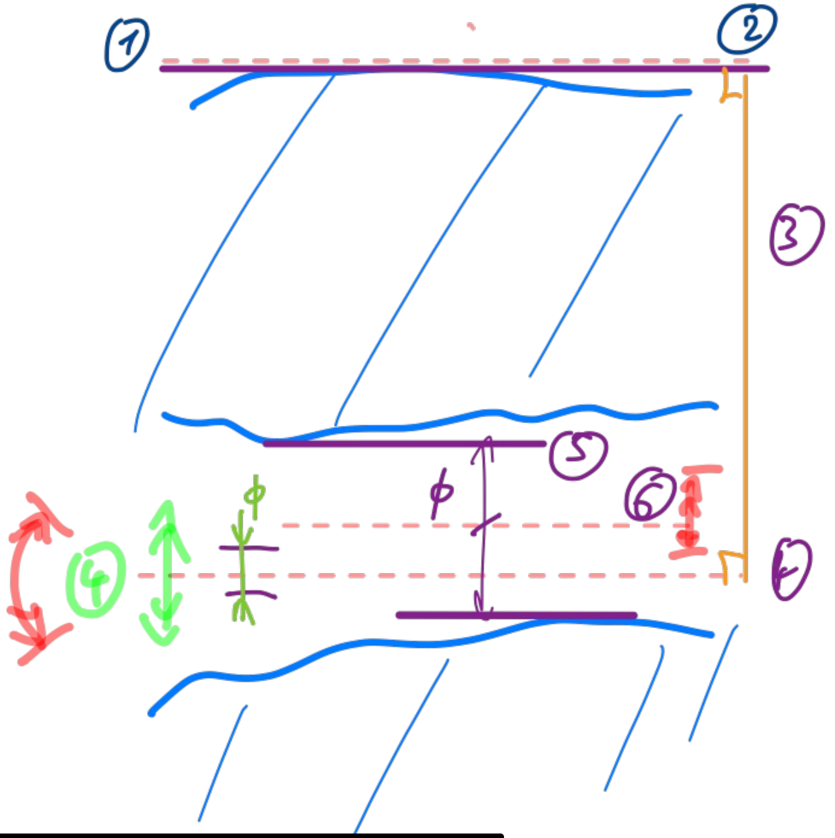


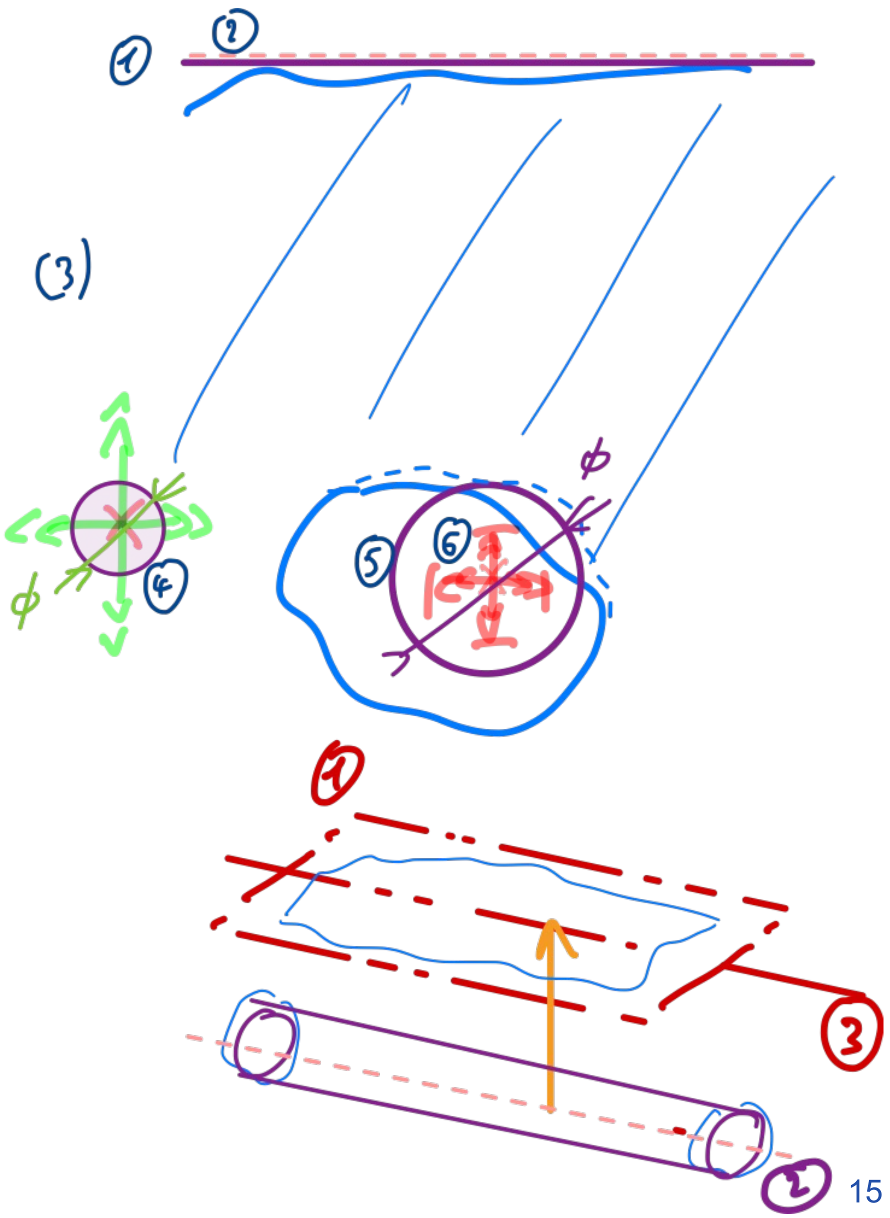
DS1 = | A[C E][S V] | B[G E] |

C: minimax
E: external to material
SV: size variable
G: gaussian (least squares)

In which order the establishment of plane and axis?

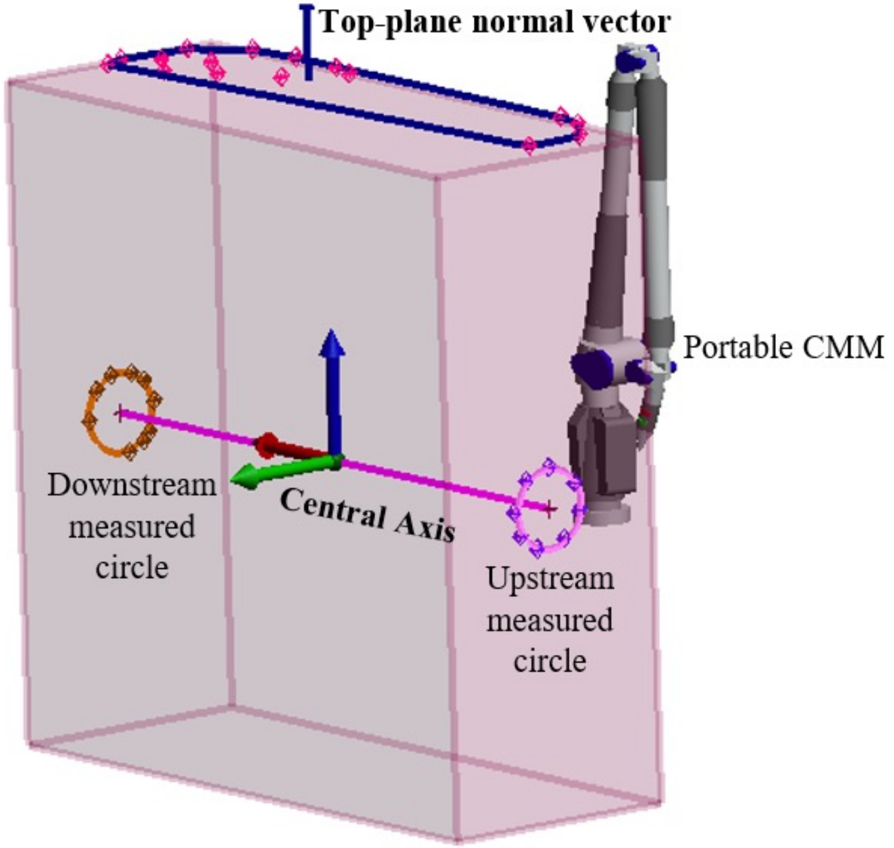
Secund possibility
B: starting with the plane

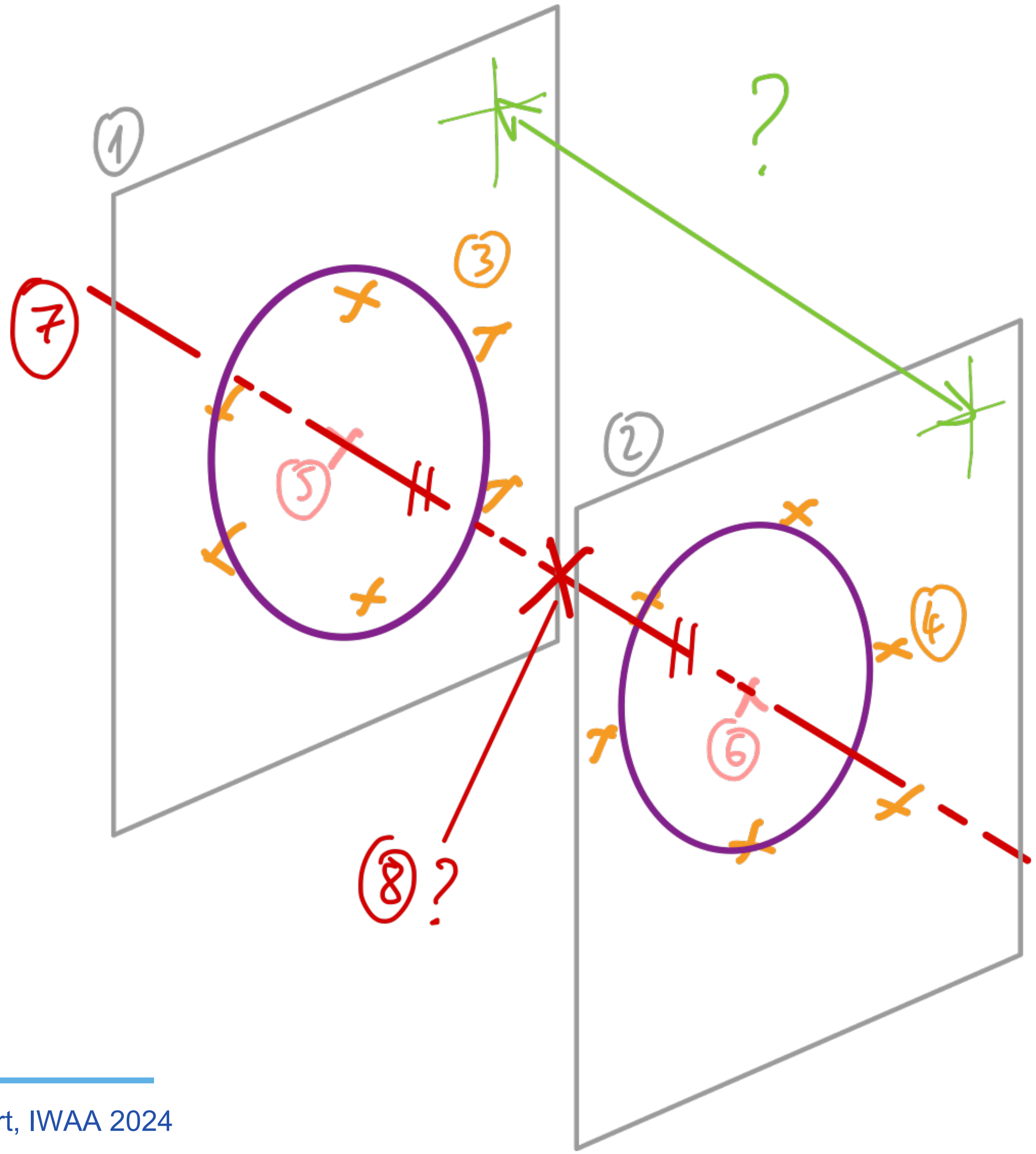




D S2 = B [G E] | A [C E] [S V]

And what about the “center” of the CS?

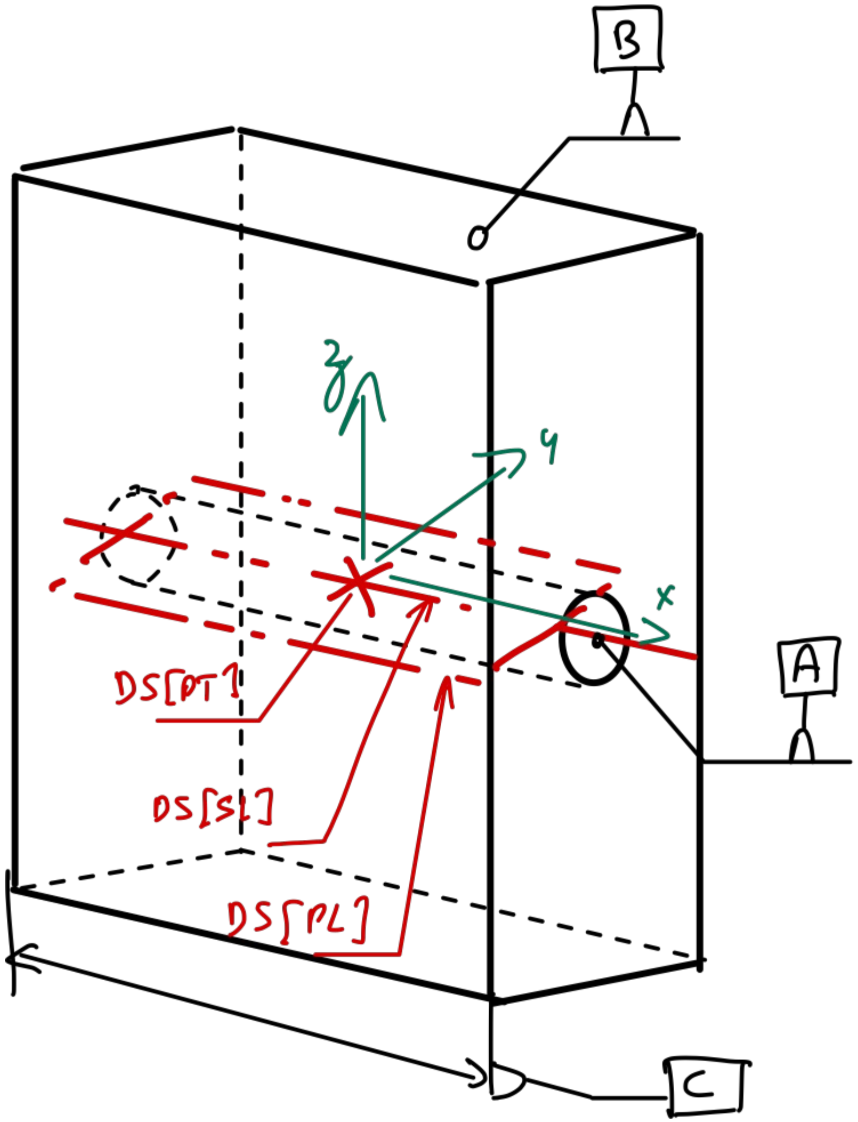


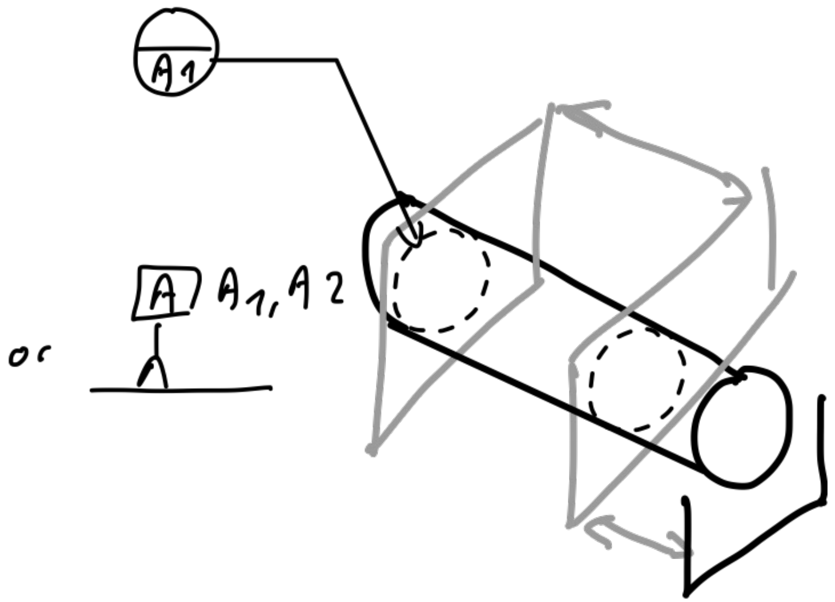


A (more) complete and functional (?) explicitation

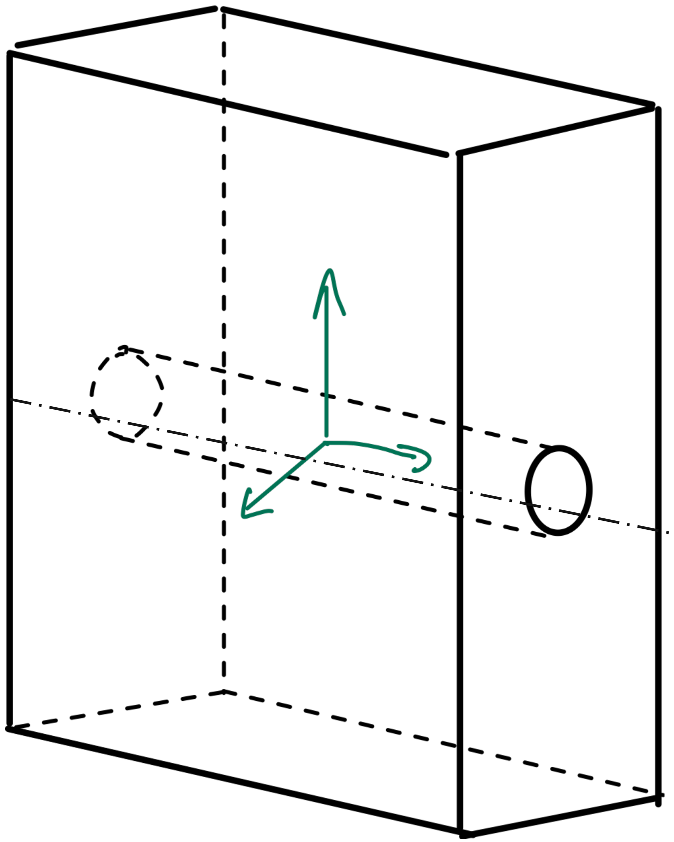
DS3 = A[CE][GM] | B[CE] | C[GM]

CS3 : DS3

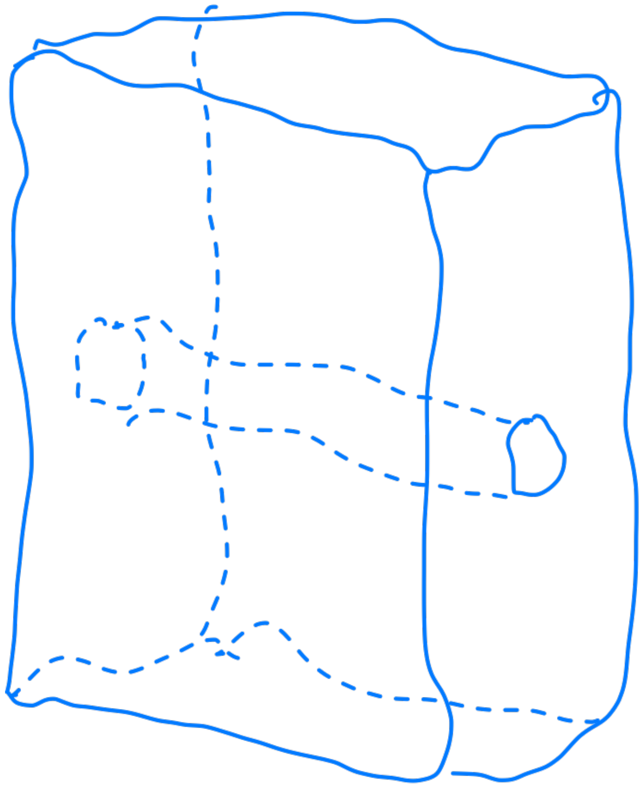




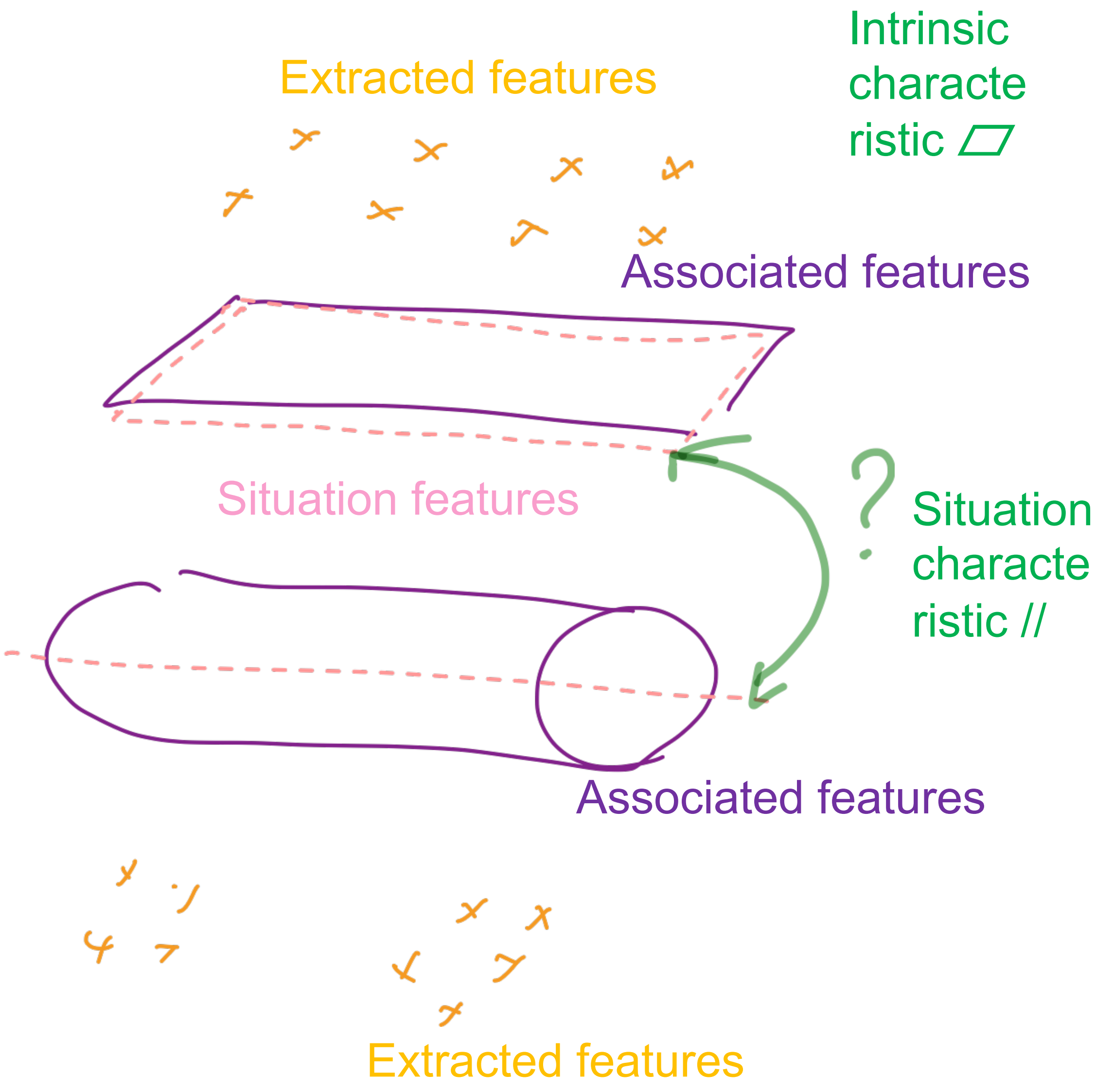
Take away: what is *explicit*, what is *implicit* and should not be



Nominal (ideal) features



Real integral features
from skin model or real part



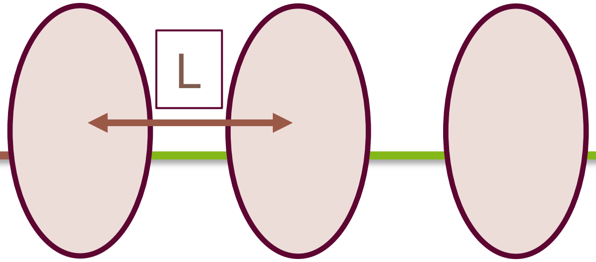
A kind advice to conclude, if I may…

- If, as a verifier (a metrologist, a surveyor), or even as a producer, I am tempted to answer these implicit questions, on the behalf of those who (should) know and fix them, it means that I am starting **interpreting**. Guessing. Inventing. Drifting. Potentially diverging. *No more univocal.*
- Is it a good idea to take on their shoulders answers to questions that should, must, *shall* be addressed by the designer?
  - "*I would prefer not to.*" (Melville). Well, just don't.
- Then, how do I get these answers? **From the TPD**
  - Better to ask them to be expressed with ISO GPS (or GD&T) language
- So what?
  - Require, request, *demand* that these answers BE addressed by designer
  - *Train* and *accompany* people all along the chain: functional specification, design, production, verification

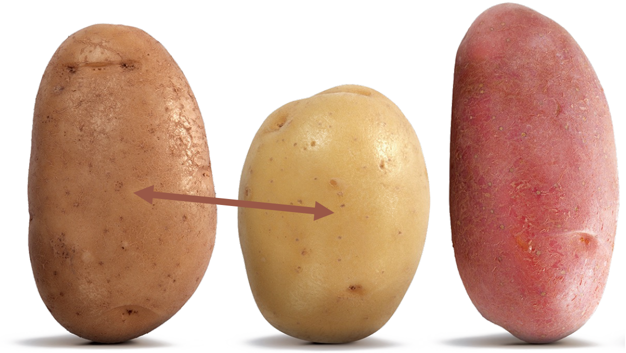
How to deal with « mutual situation »?

- Design defines surfaces with geometrical characteristics: intrinsic or situational
- Then real surfaces are manufactured
- Metrology captures points on surfaces
- Survey and alignment
  - **Focus mainly on situation characteristics…**
  - **… starting from sets of fiducial points!**
- How to deal with mutual situation?
  - **How to define situation characteristics?**
  - **For any kind of surfaces? For constellations?**
  - **How to constraint these mutual situations?**

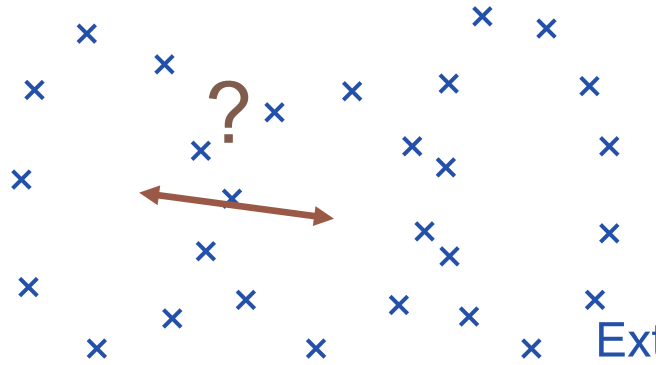
ISO 25378:2011



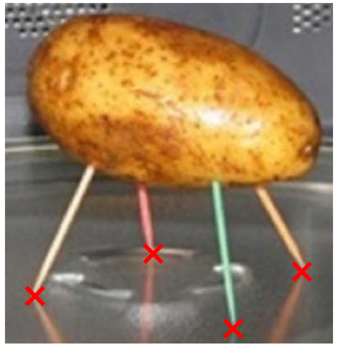
Nominal



Real



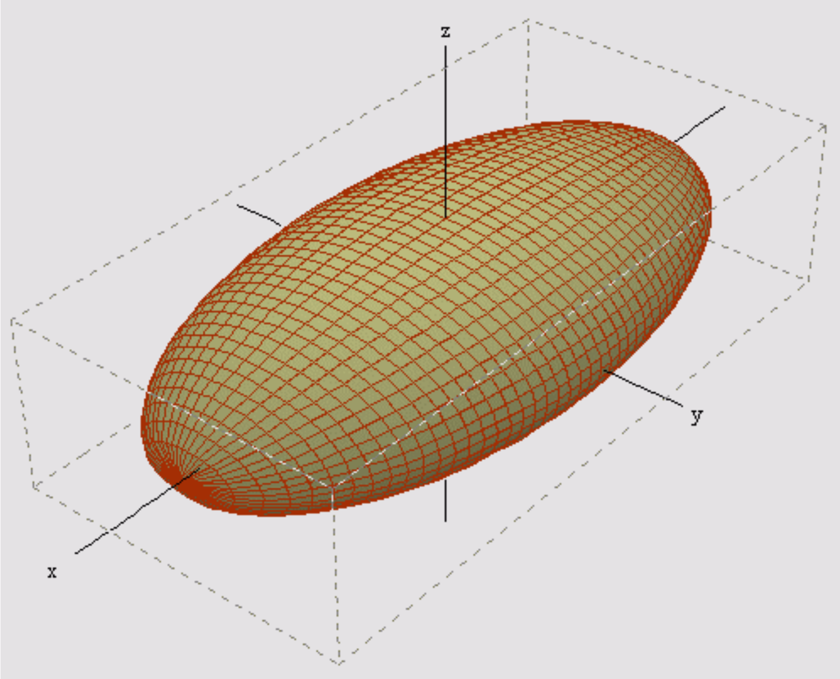
Extracted



Fiducialised?

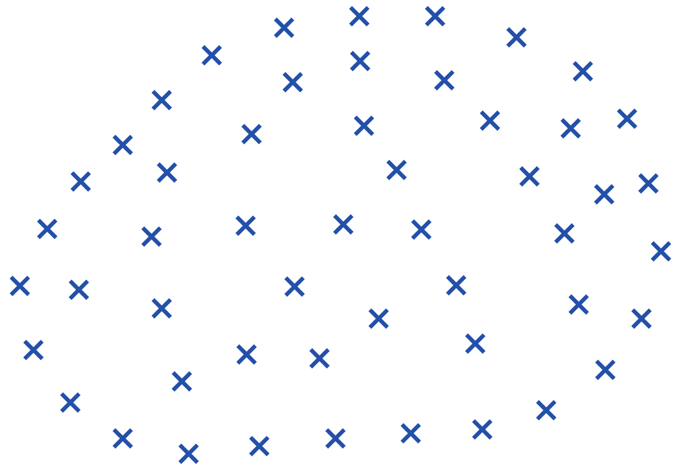
Intrinsic form and size of an “integral feature”

- How to find the (minimum) set of parameters to define the nominal feature?
- How to characterize deviations with respect to nominal?



Nominal model

Real part



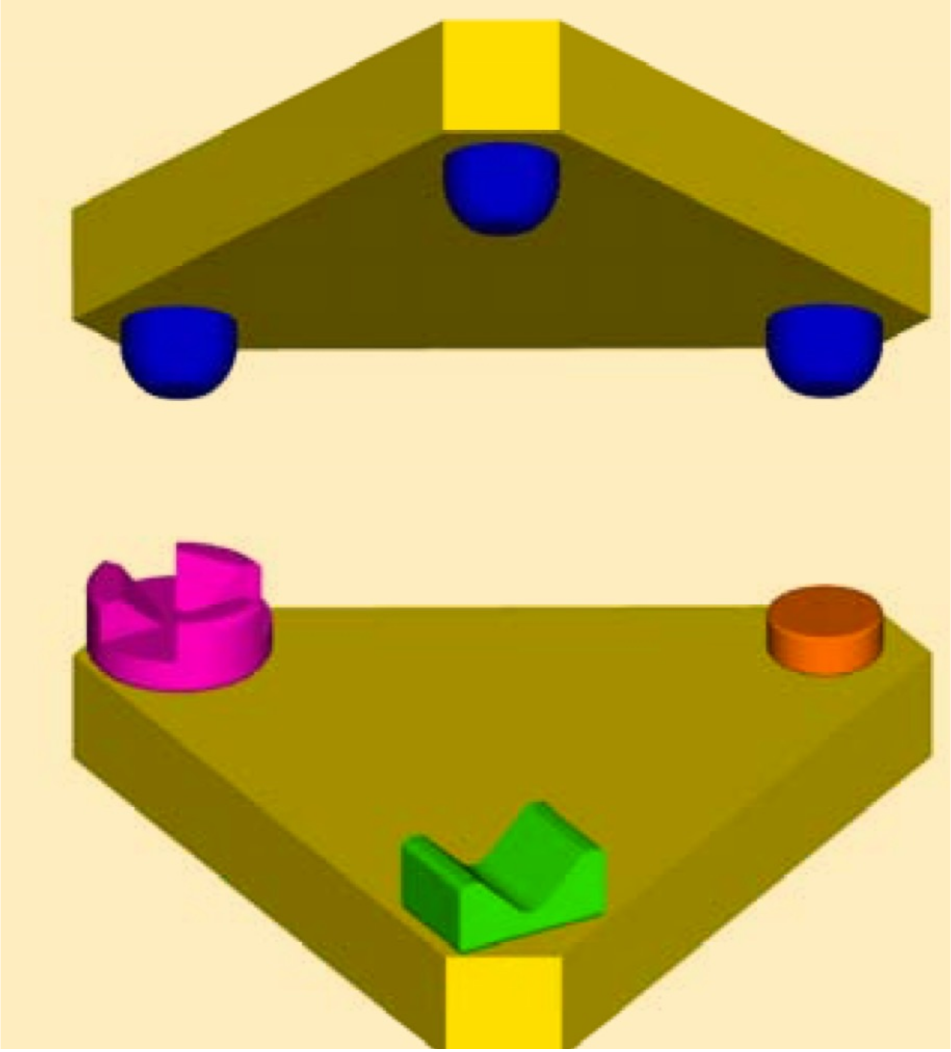
Measured part
Extracted feature
= set of points

ISO GPS situation features

- **Situation = location and orientation**
- **Which features are sufficient to determine the situation of any surface?**
- **ISO GPS situation features: « point, straight line, plane, from which the *situation* of a geometrical feature can be totally or partially defined »**

[SOURCE: ISO 17450-1:2011, 3.3.1.3 modified]

- **Origin: probably the *Kinematic System* of Kelvin (1868-1871)**



Technologically and Topologically Related Surfaces (TTRS) model

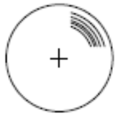
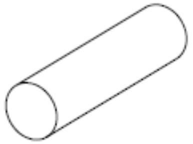
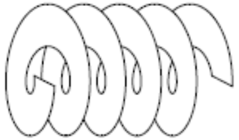
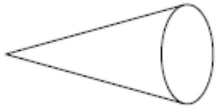
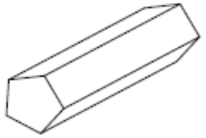
Invariance classes (ISO 17450-1)

Gives situation feature: concept of a **minimum set of a point, a straight line, and a plane** that ensures the surface invariance

ISO/DIS 20223:2024(en)

Table 5 — List of type identifiers of the type of a minimum set of situation features

	Type of the minimum set of situation features	Type identifier
Minimum set of a single situation feature	Point (**P**oin**T**)	[PT]
	Straight line (**S**traight **L**ine)	[SL]
	Plane (**PL**ane)	[PL]
Minimum set of a pair of situation features	Point in plane (poin**T** **i**n **P**lane)	[TiP]
	Point on line (poin**T** **o**n **L**ine)	[ToL]
	Line in plane (**L**ine **i**n **P**lane)	[LiP]
Complete minimum set of situation features	Point on line in plane (poin**T** **o**n **L**ine **i**n **P**lane)	[ToLiP]

Invariance class	Invariance degrees for which the surface is invariant	Illustration	Situation features	Example of types of surfaces
Spherical	3 rotations around a point		Point	Sphere
Planar	1 rotation perpendicular to the plane and 2 translations along 2 lines of the plane		Plane	Plane
Cylindrical	1 translation and 1 rotation around a straight line		Straight line	Cylinder
Helical	Combination of 1 translation and 1 rotation around a single straight line		~~Helix~~ ✗	Helical surface with a basis of involute to a circle
Revolute	1 rotation along a straight line		Straight line Point + ...	Cone Torus
Prismatic	1 translation along a line of a plane		Plane Straight line	Prism with an elliptic basis
Complex	None		Plane Straight line Point	Bezier surface based on an unstructured cloud of points in space

Invariance classes and corresponding situation features

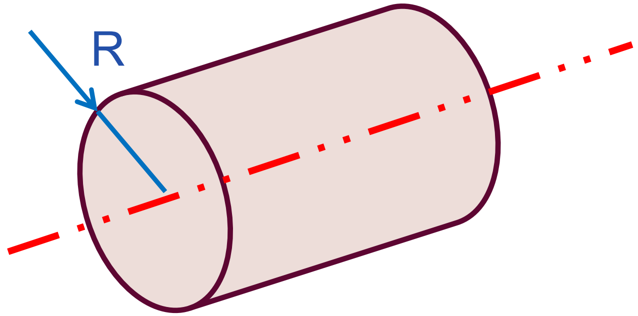
Clément, A., Rivière, A., Serré, P., & Valade, C. (1998). The TTRSs: 13 constraints for dimensioning and tolerancing. Geometric design tolerancing: theories, standards and applications, 122-131.

Extension of single situation features to ToLiPs

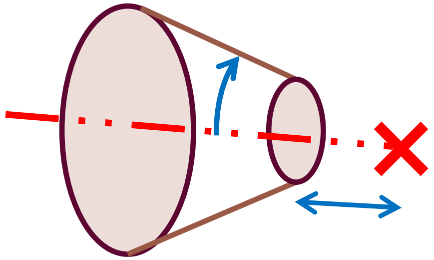
- **A triplet of a point, a line and a plane satisfying**

'poinT on Line in Plane', i.e. T∈L⊂P

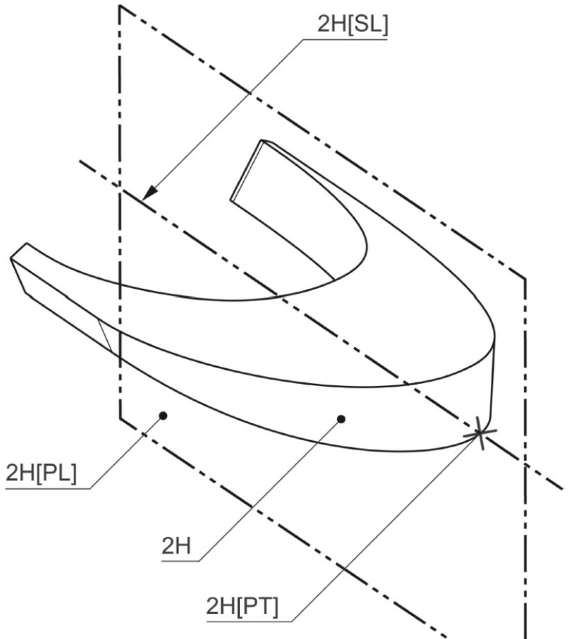
- **Allows an explicitation of situation features for any types of geometrical features depending on their invariance class**



A feature of invariance class *Cylindrical*: a single situation feature, one intrinsic parameter



A feature of invariance class *Revolut*: a pair of situation features, two parameters



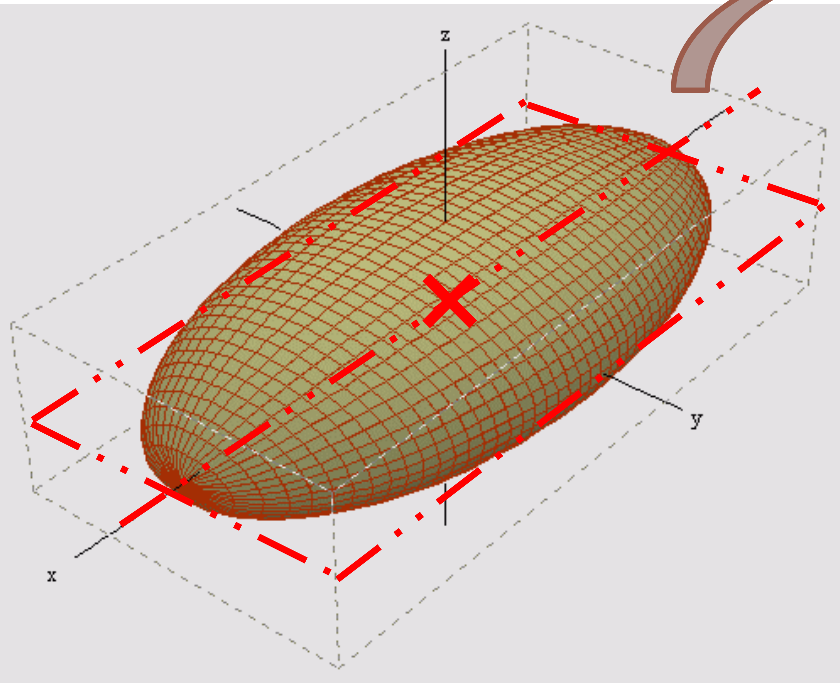
A feature of invariance class *Complex*: a minimum set of three situation features, and many parameters

Nominal and actual situation features

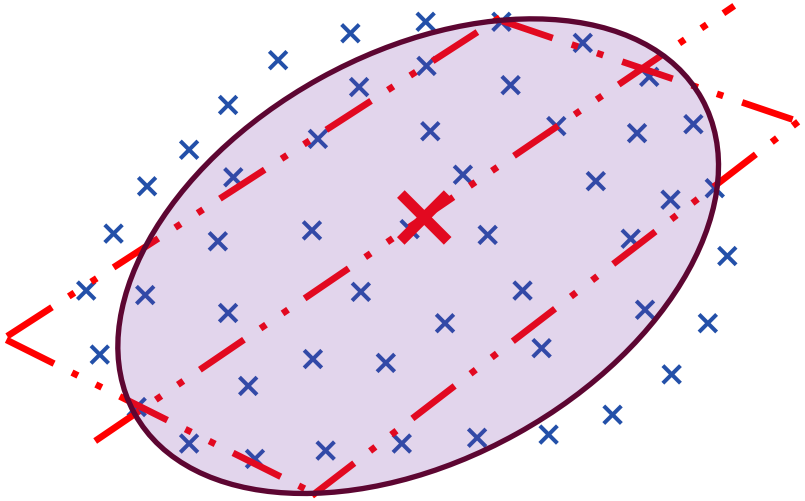
Association

(e.g. here: with Gaussian criterion – least squares sum – and without material constraint [GM]; + without situation constraint; + with offset of intrinsic dimensions “size variable”)

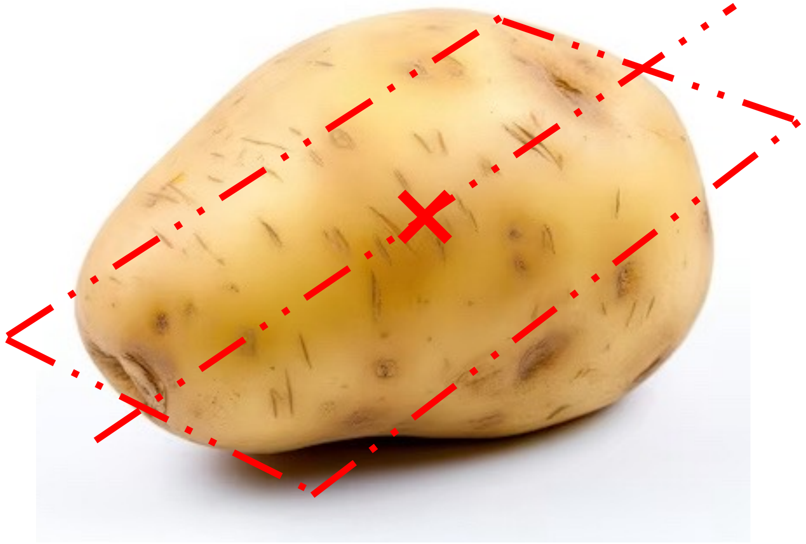
Assumes that the nominal is known



Nominal situation features



Situation features of the associated feature



Actual situation features of the real integral feature

ToLiP: a bridge between worlds

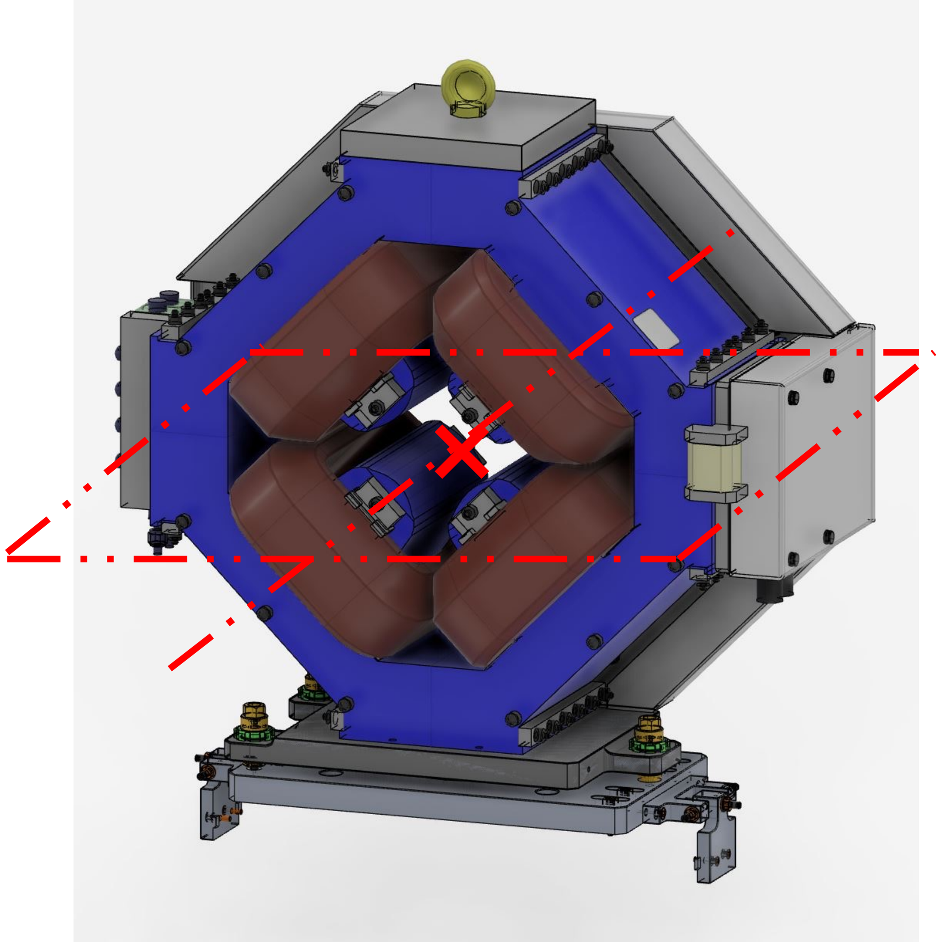
- □ the world of *design* (features and characteristics)
- □ the world of *metrology* (points and coordinate systems)

through the *world* of manufacturing (toolpaths, tool settings)

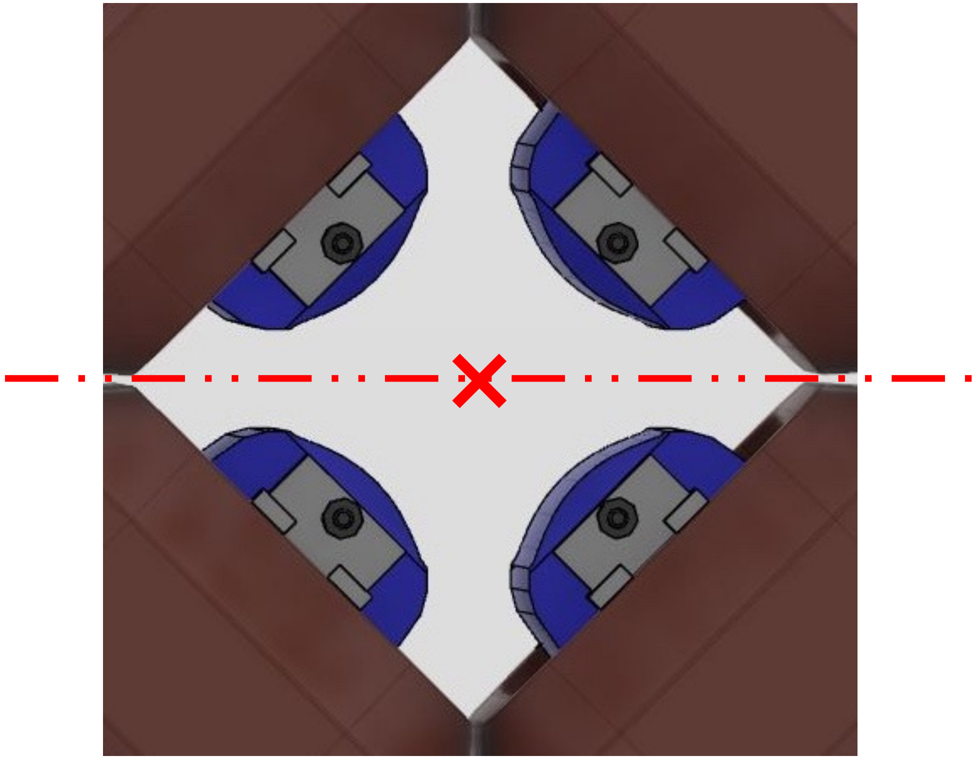
ToLiP: a tool developed from real needs, and under standardization

"Situation features": how to characterize the situation

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



Pole "profile": invariance class **complex** (convex surfaces)

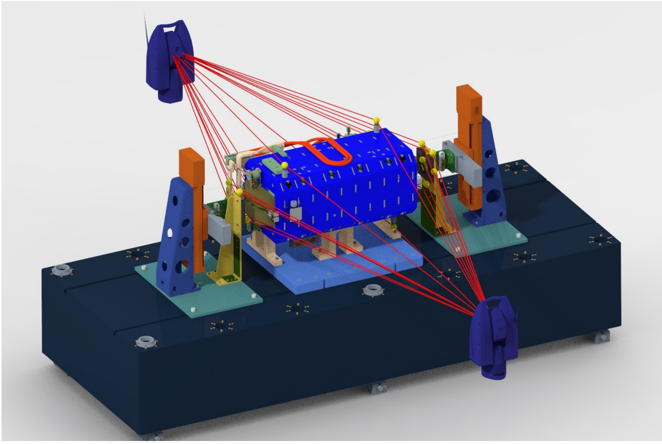


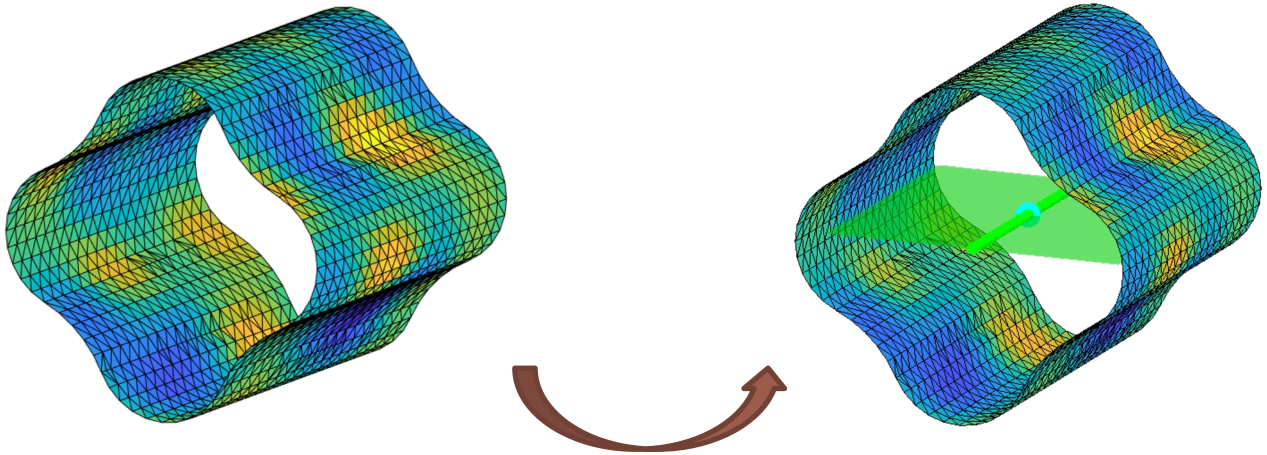
=> Minimum set of situation features: [ToLiP]

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**

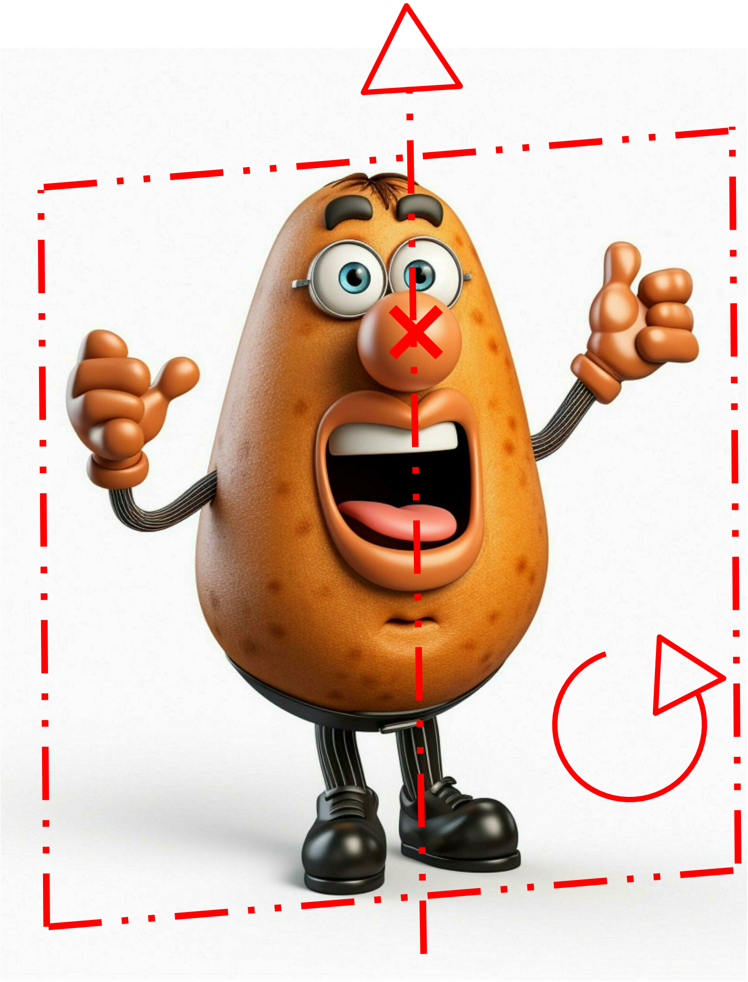
Or, by fiducialization, by *association* between the nominal and the real magnetic field!





Situation features determination for a geometrical feature of prismatic invariance

ToLiP with *positive* directions of situation features



- A way to deal with “chirality”
- Defined in ISO/DIS 20223:2024, it enables to fully establish an *oriented* coordinate system

Figure 6 explains the implicit direction of the situation features of type [SL] and of type [PL] induced by the representation of the coordinate system of Figure 5.

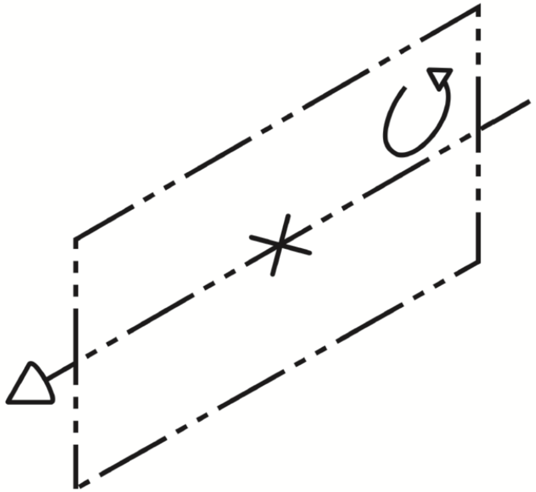
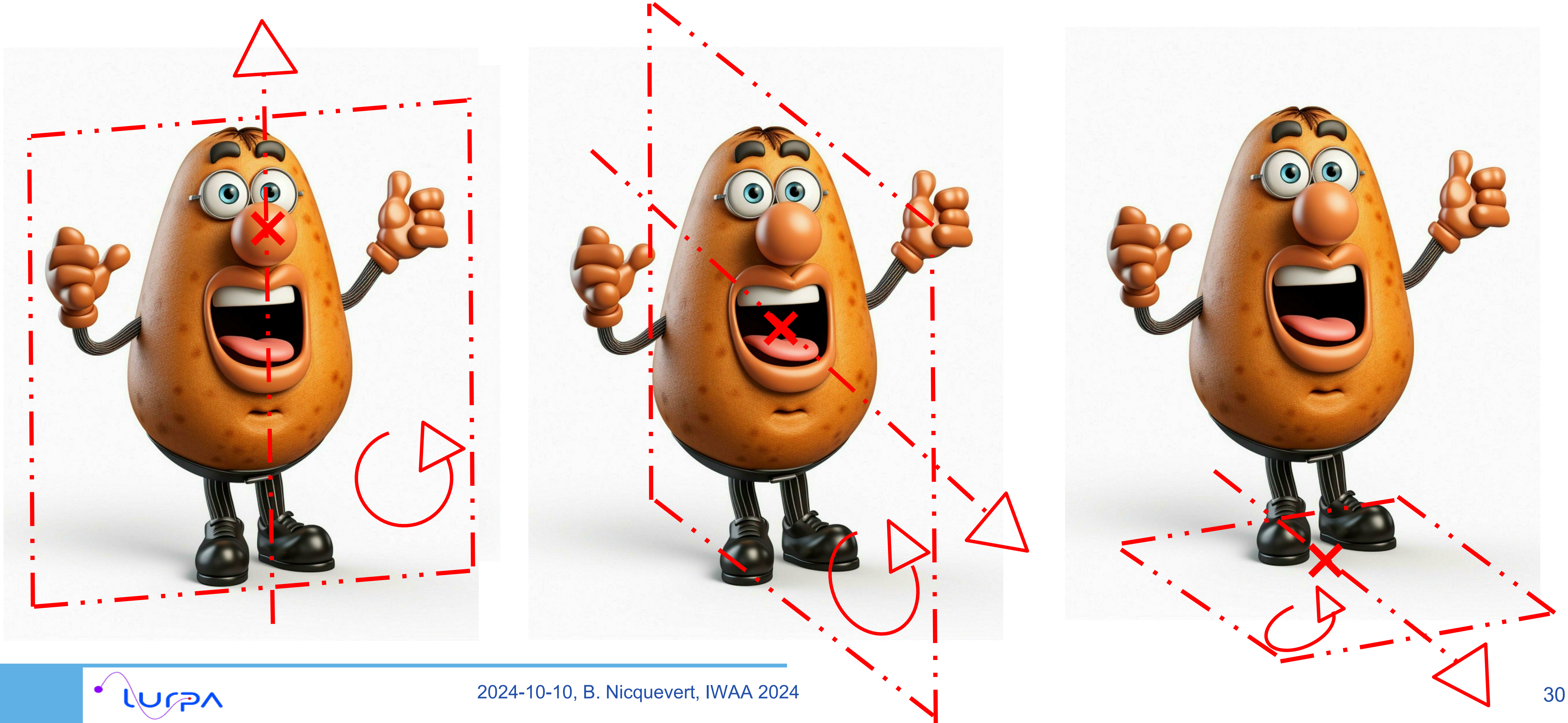


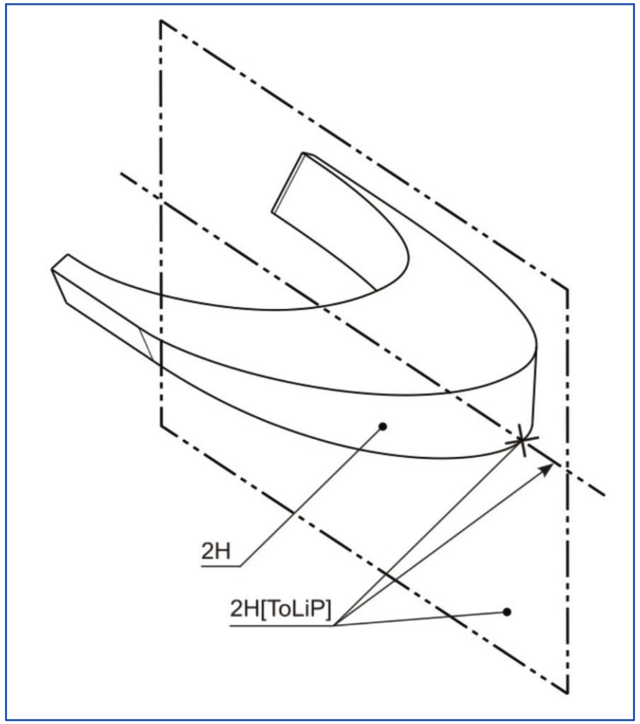
Figure 6 — Interpretation of the positive directions of the situation features indirectly defined by the representation of Figure 5

Explicit representation of the ToLiP

- Three possible choices (out of *many*) for the ToLiP of Mr Potatoe



An ISO standard to represent and identify situation features



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

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

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

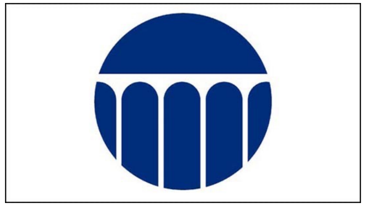
ICS: 01.110

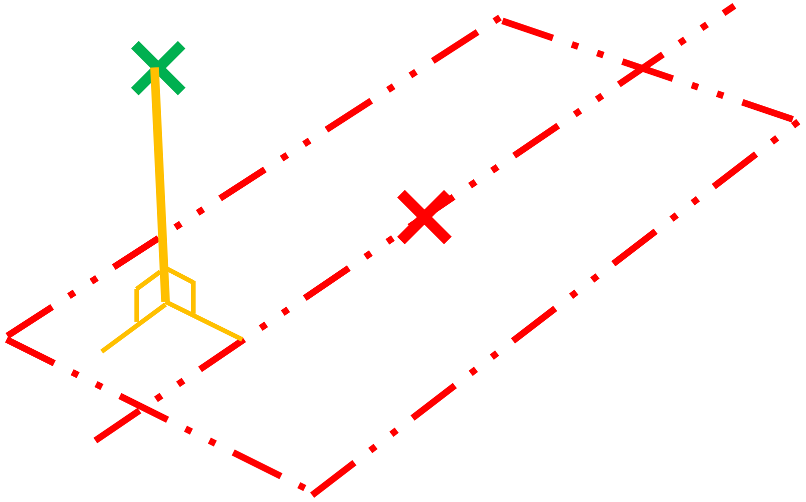
- A project developed starting from ESS and CERN needs
- Currently under public consultation
- *Please* send your comments through your national committee
  - AFNOR, ASME, BSMI, BS, DIN, DS, JISC, SAC, SCC, SIS, SNV, UNE, UNI…
  - Deadline: by end of November = now!

ToLiPs and coordinate systems

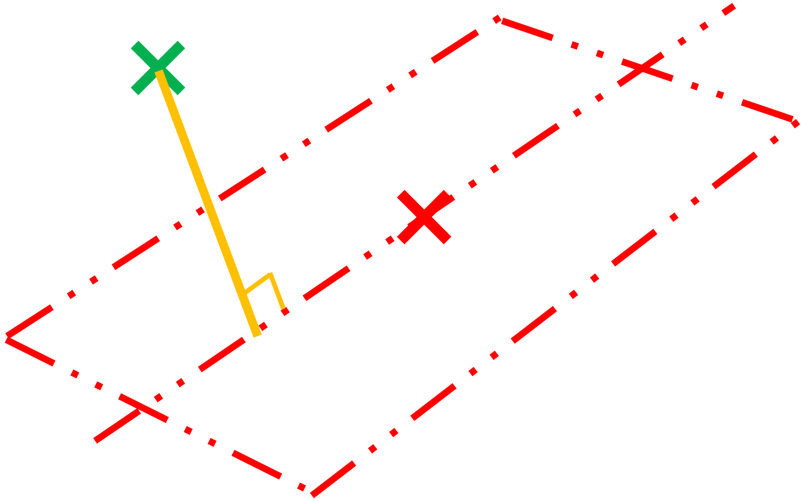
□ How to define the distance from a point to a (complete) ToLiP?

e.g. a datum system (DS)

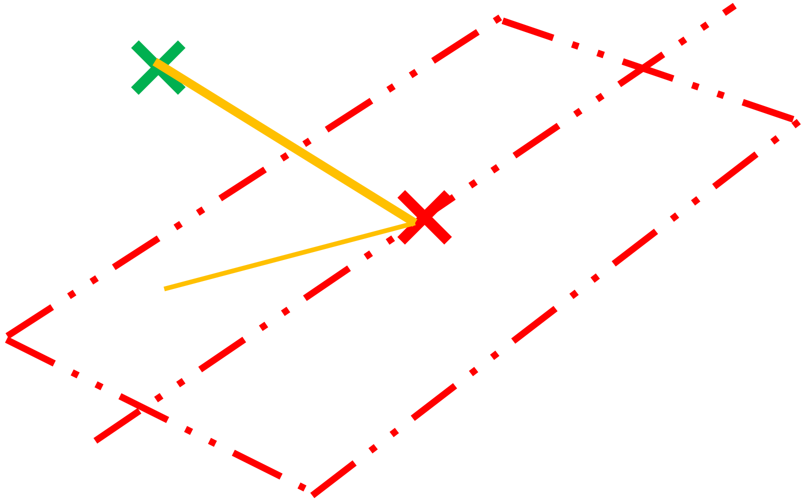




Distance from point to **plane**: induces a cartesian coordinate system



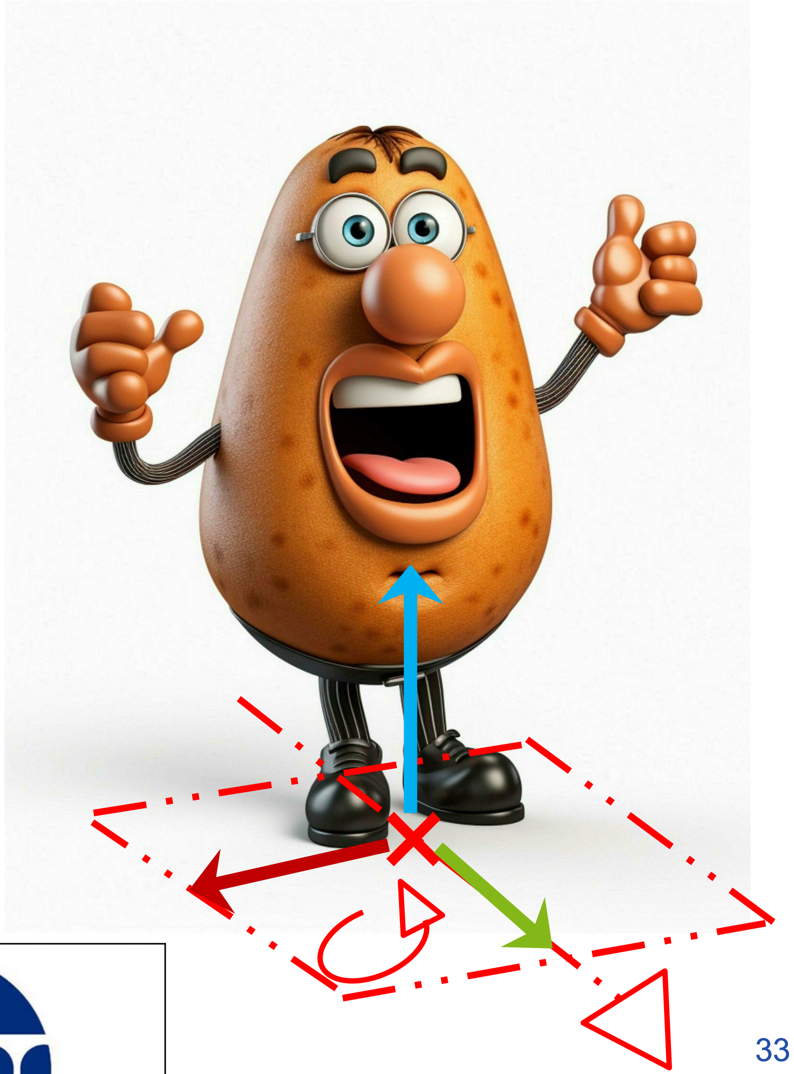
Distance from point to **straight line**: induces a polar coordinate system



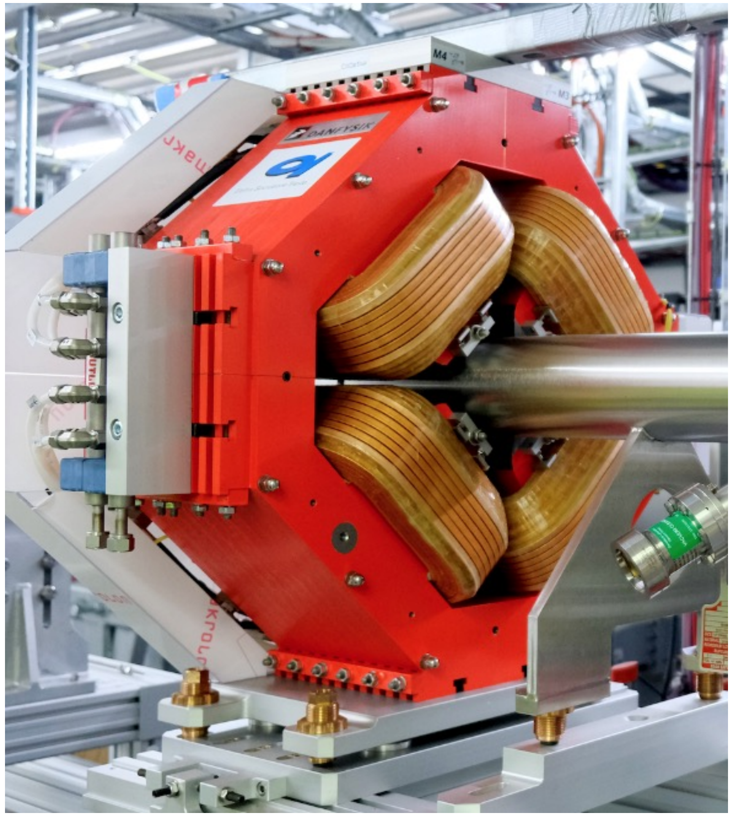
Distance from point to point: induces a spherical coordinate system

Take away on ToLiP and CS

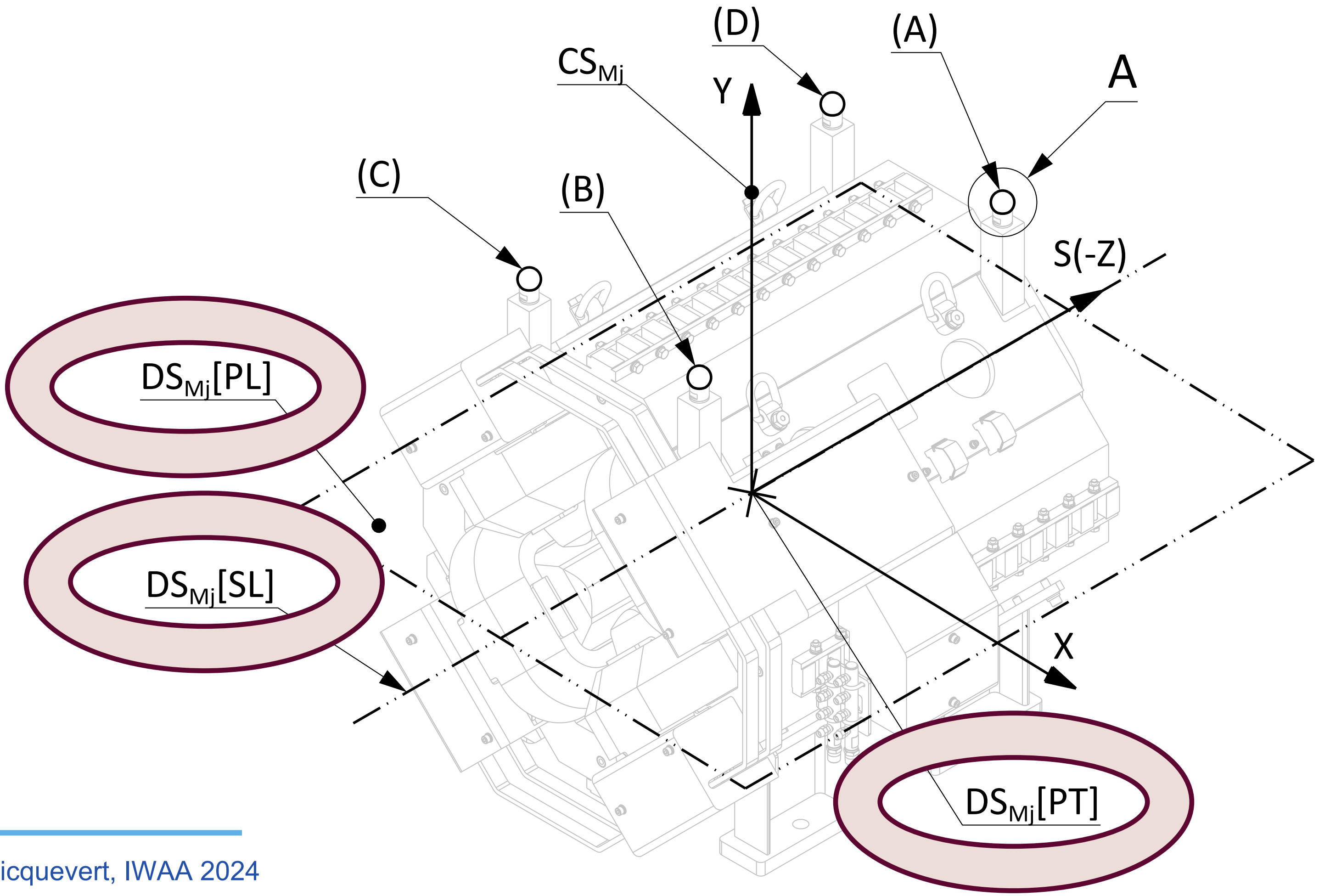
- A complete ToLiP is a minimum set made of three situation features of different types, with condition
  - **point on line in plane**
- A ToLiP does not depend on any coordinate system
- This is the other way round: **a Coordinate System is established on a ToLiP**
- Nota: a ToLiP can be established on any set of integral features (not only datum features)



Explicit representation and indication of situation features



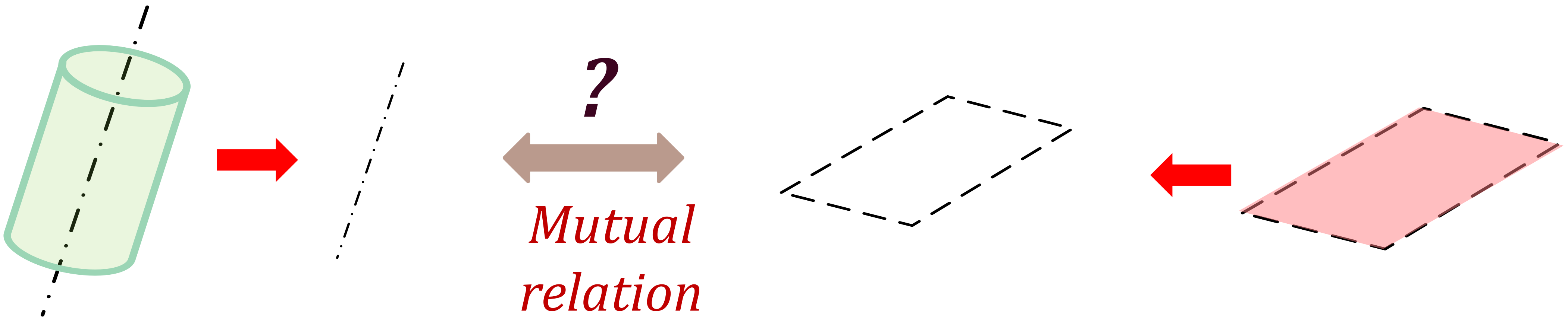
A complete ToLiP defines the situation of the surfaces upon which it is established



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

Mutual situation of single situation features?

Example



Cylindrical surface

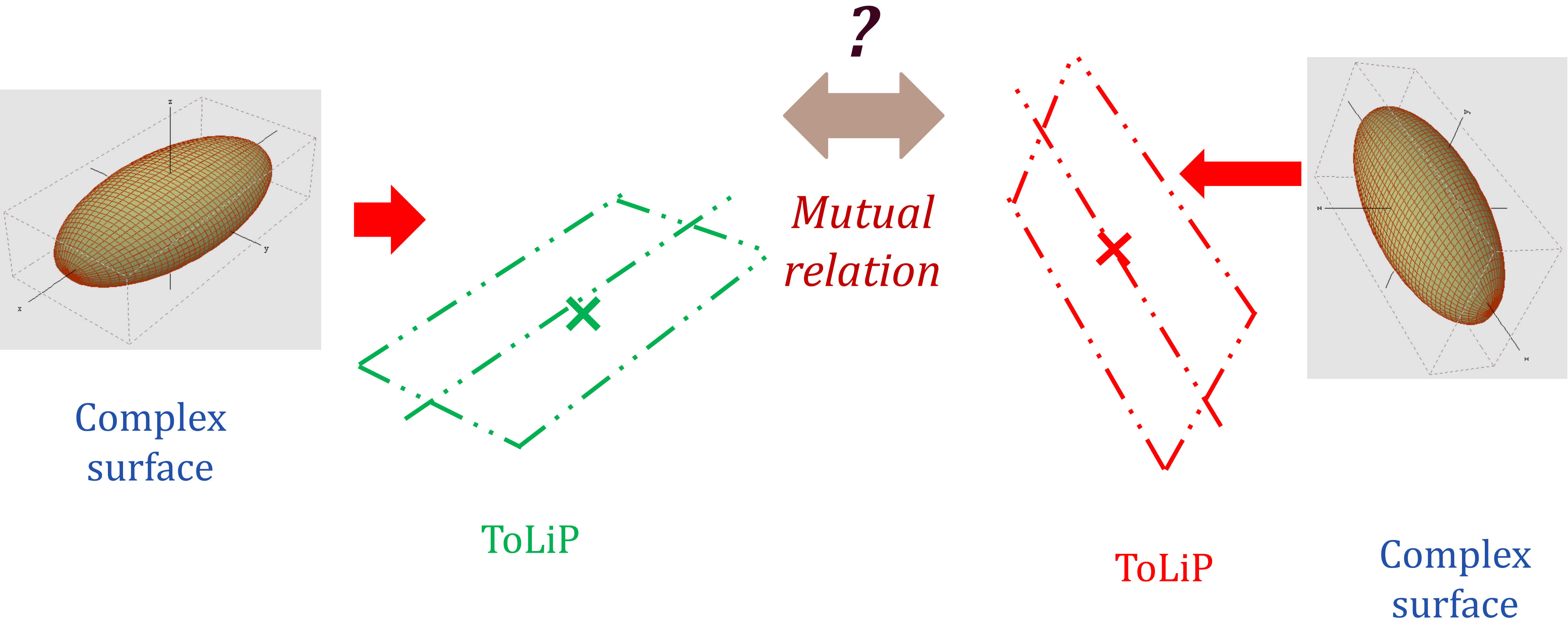
Situation Feature: Line

Situation Feature: Plane

Planar surface

Mutual situation between any two ToLiPs?

General case



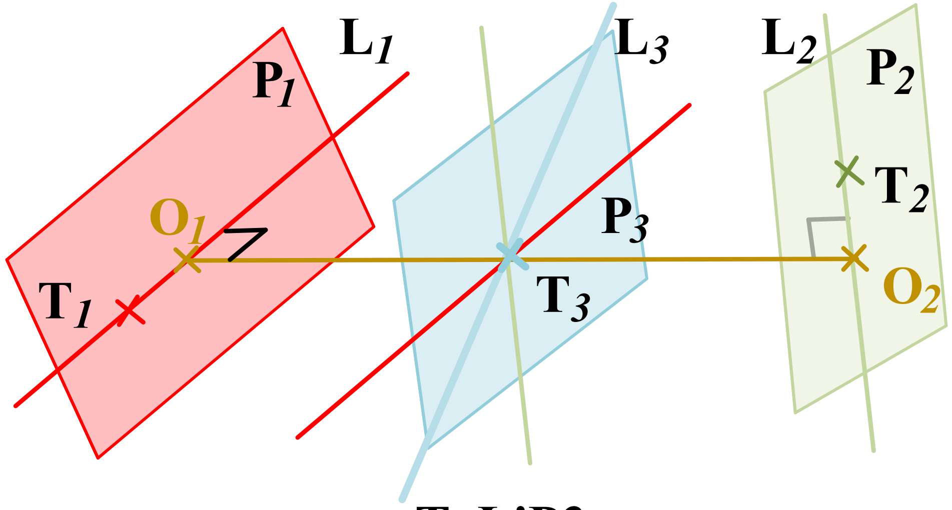
A new tool: CoToLiP, as a Composition of two ToLiPs

Mathematical representation of the mutual situation of two ToLiPs: CoToLiP

Composition of two ToLiPs:

ToLiP3 = ToLiP1 ⊕ ToLiP2,

CoToLip is a ToLiP along with *six* parameters (distances and angles)



CoToLiP:

- A commutative operator,
- Handles both relative or absolute mutual situation

$d(\mathbf{O}_1, \mathbf{T}_1)$, $\varphi(\mathbf{P}_1, \mathbf{P}_3)$,
$d(\mathbf{O}_2, \mathbf{T}_2)$, $\varphi(\mathbf{P}_2, \mathbf{P}_3)$,
$d(\mathbf{O}_1, \mathbf{O}_2)$, $\varphi(\mathbf{L}_1, \mathbf{L}_2)$

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

Mock-up demo

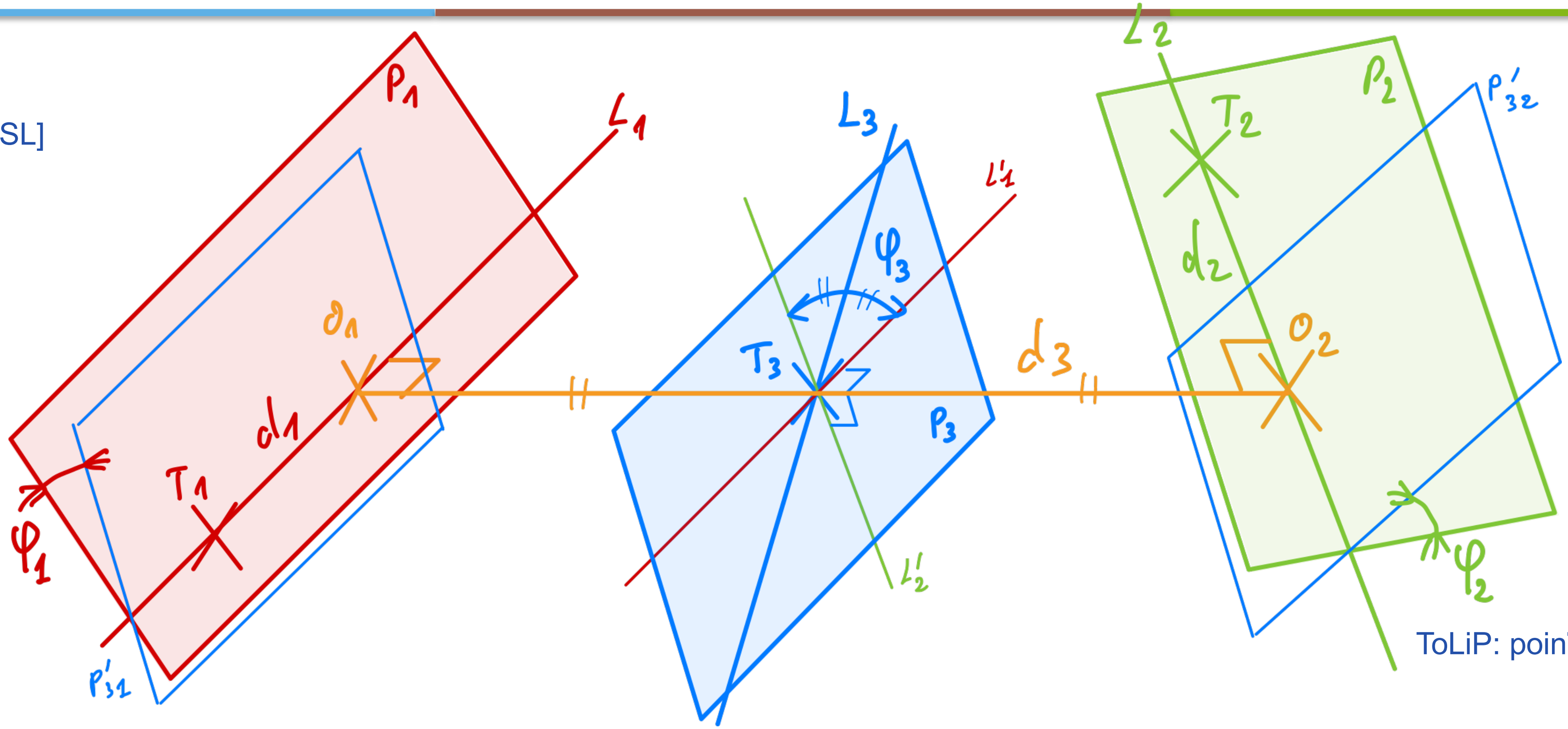
Lund, Sept 2024:

- demo of the mock-up
- prepared by ESS SAM team
  (tack så mycket, mina vänner!)
- to ISO/TC213 (GPS) experts

@ IPAC, Venice, May 2023

Handling mutual situation of two sets of situation features with CoToLiP

T_i: poinT [PT]
L_i: straight Line [SL]
P_i: Plane [PL]



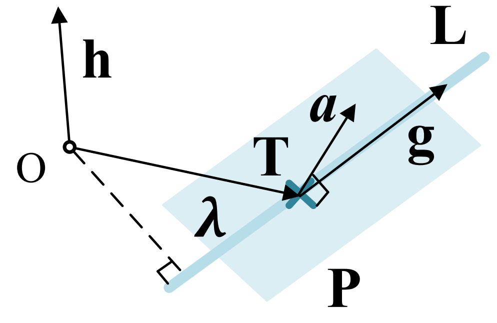
ToLiP: poinT on Line in Plane
$T_i \subset L_i \subset P_i$

Definition of the **CoToLiP** (in blue), composition of two sets (red and green) of situation features **ToLiP**.
O_1O_2 is the common perpendicular to L_1 and L_2; T_3 is the middle of $[O_1O_2]$; P_3 is perpendicular to O_1O_2 containing T_3; L'_i are orthogonal projections of L_i on P_3; L_3 is the bisector line of L'_1 and L'_2; P'_{3i} are translations along (O_1O_2) of P_3 containing L_i (also known as antiprojections on L_i).
The *six parameters of mutual situation*: mutual position d_1, d_2, d_3; mutual orientation φ_1, φ_2, φ_3 are directly derived [18].
The CoToLiP is an operator. Input features: ToLiP1 and ToLiP2; output features: ToLiP3 and the six parameters of mutual situation as output features.
ToLiP3 = *CoToLiP* (ToLiP1; ToLiP2) = *CoToLiP* (ToLiP2; ToLiP1) = *CoToLiP* 1< >2

B. Nicquevert, “Les éléments de situation. Sur quelques éléments fondamentaux de « tolipologie »” (in French), 2023, CERN, Geneva, Switzerland, EDMS 2817750, preprint HAL-03996426, March 2023.

The math of CoToLiP: behind the "behind the curtain"

Developing underlying mathematical models, using *PGA* (Projective Geometric Algebra) and Flag manifolds



Geometric product: the extension of elementary algebra to new binary operation

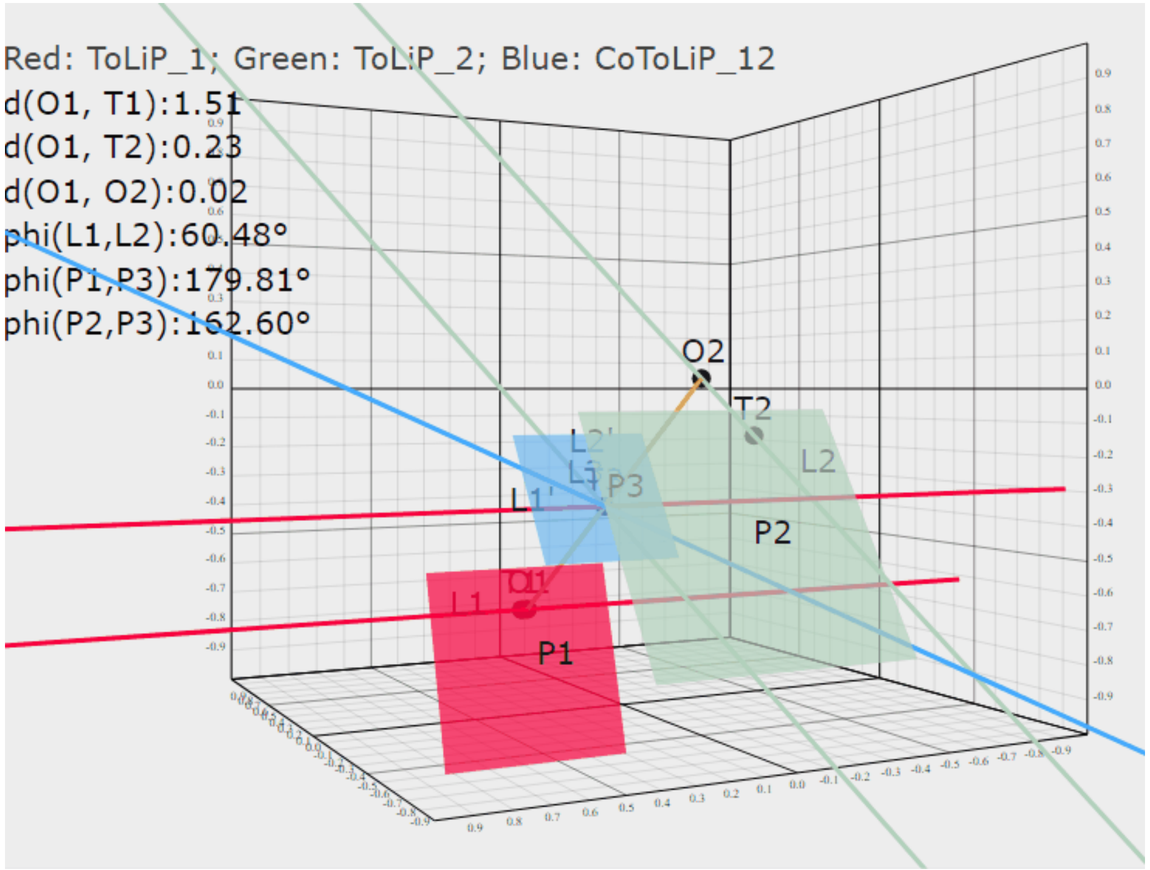
$$AB = A \cdot B + A \wedge B$$

ToLiP using Flag Theory: (**g**, **h**, **a**, λ)

Elementary mutual situation parameters

	Point $\mathbf{T}_2$	Plane $\mathbf{P}_2$	Line $\mathbf{L}_2$
Point $\mathbf{T}_1$	d: $\|\| \mathbf{T}_1 \wedge \mathbf{T}_2 \|\|$	d: $\|\| \mathbf{P}_2 \vee \mathbf{T}_1 \|\|$	d: $\|\| \mathbf{T}_1 \wedge \mathbf{T}_1' \|\|$
Plane $\mathbf{P}_1$	d: $\|\| \mathbf{P}_1 \vee \mathbf{T}_2 \|\|$	d: $\|\| \mathbf{P}_1 \vee \mathbf{P}_2 \|\|$ or φ: $\sin^{-1}(\mathbf{P}_1 \vee \mathbf{P}_2)$	d: $\|\| \mathbf{P}_2 \wedge \mathbf{T}_1 \|\|$ or φ: $\sin^{-1}[(\mathbf{L}_1 \vee \mathbf{P}_2) \cdot \mathbf{L}_1 \vee \mathbf{P}_2]$
Line $\mathbf{L}_1$	d: $\|\| \mathbf{T}_2 \wedge \mathbf{T}_2' \|\|$	d: $\|\| \mathbf{P}_1 \wedge \mathbf{T}_2 \|\|$ or φ: $\sin^{-1}[(\mathbf{L}_1 \vee \mathbf{P}_2) \cdot \mathbf{L}_1 \vee \mathbf{P}_2]$	d: $-(\mathbf{g}_1 \cdot \mathbf{h}_2 + \mathbf{h}_1 \cdot \mathbf{g}_2) + \|\| \mathbf{g}_1 \times \mathbf{g}_2 \|\|$ and φ: $\cos^{-1}(\mathbf{g}_1 \cdot \mathbf{g}_2)$

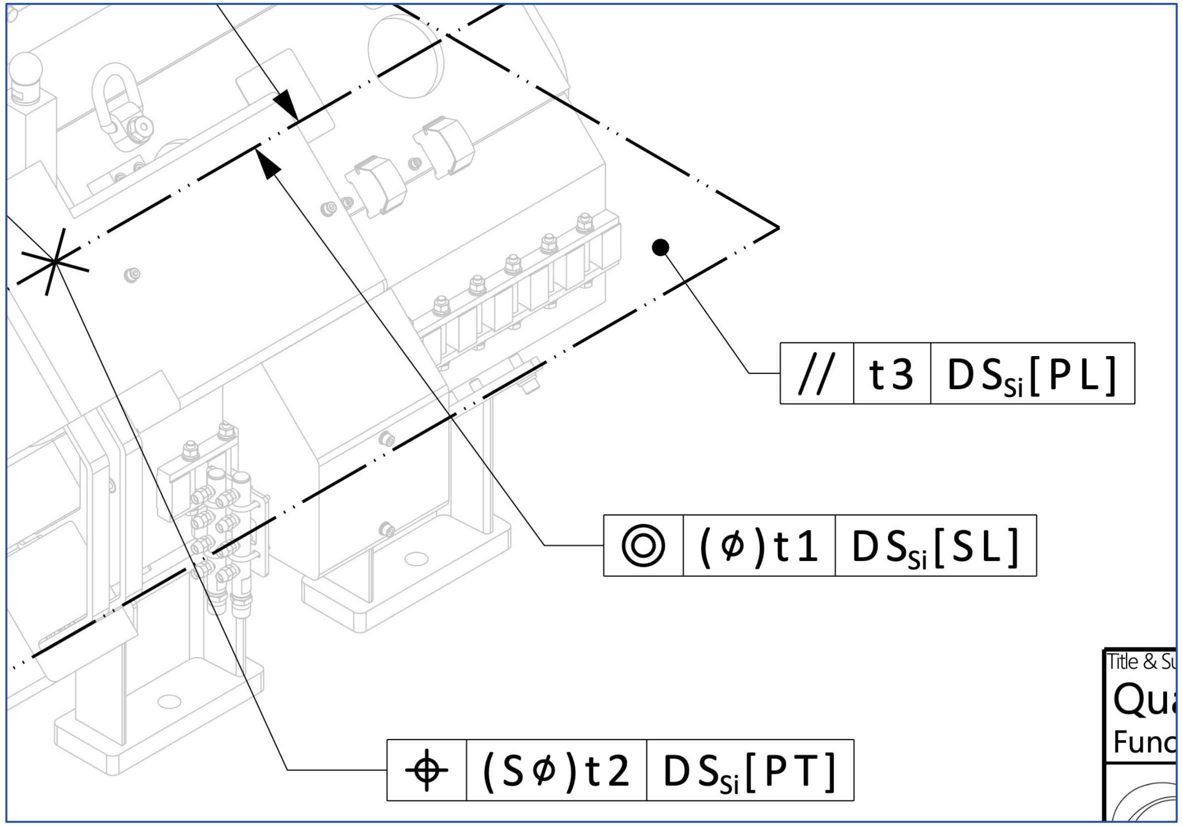
$\|\|\cdot\|\|$ represents the Euclidean norm; $\mathbf{T}_i'$ is the projection point of $\mathbf{T}_i$ onto $\mathbf{L}_j$.

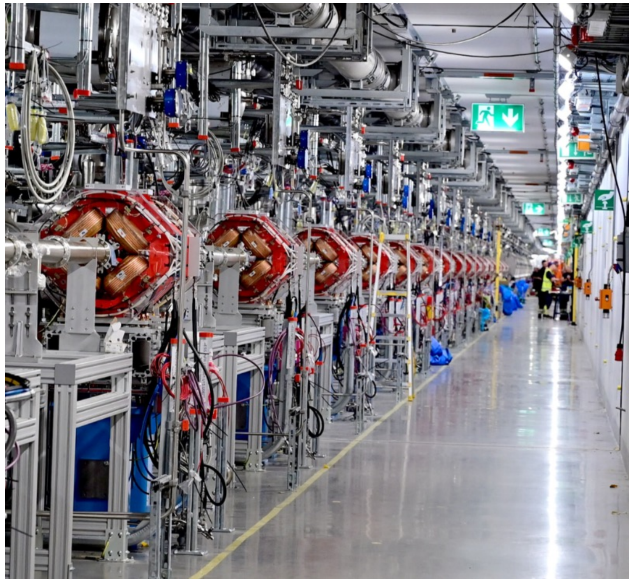


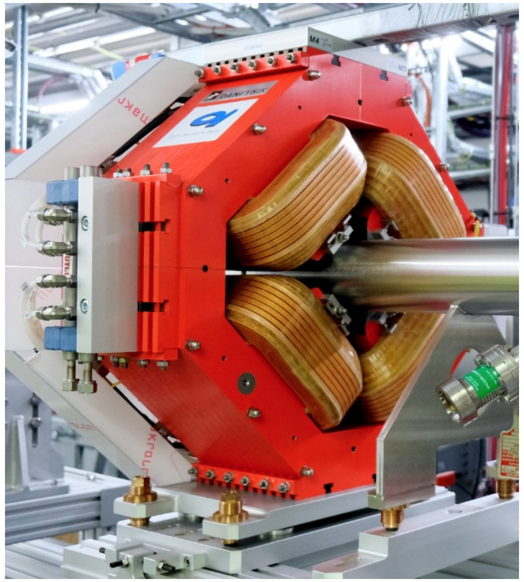
Qie, Y., Nicquevert, B., Anwer, N. "Functional specification of complex assemblies using projective geometric algebra". *CIRP Annals*, vol. 73, 1, pp. 105-108 (2024). https://doi.org/10.1016/j.cirp.2024.04.059

Absolute mutual situation: situation features as "toleranced features"

- □ Mutual situation between a "tolerance feature" and a datum system
- □ A generalization of "derived" features



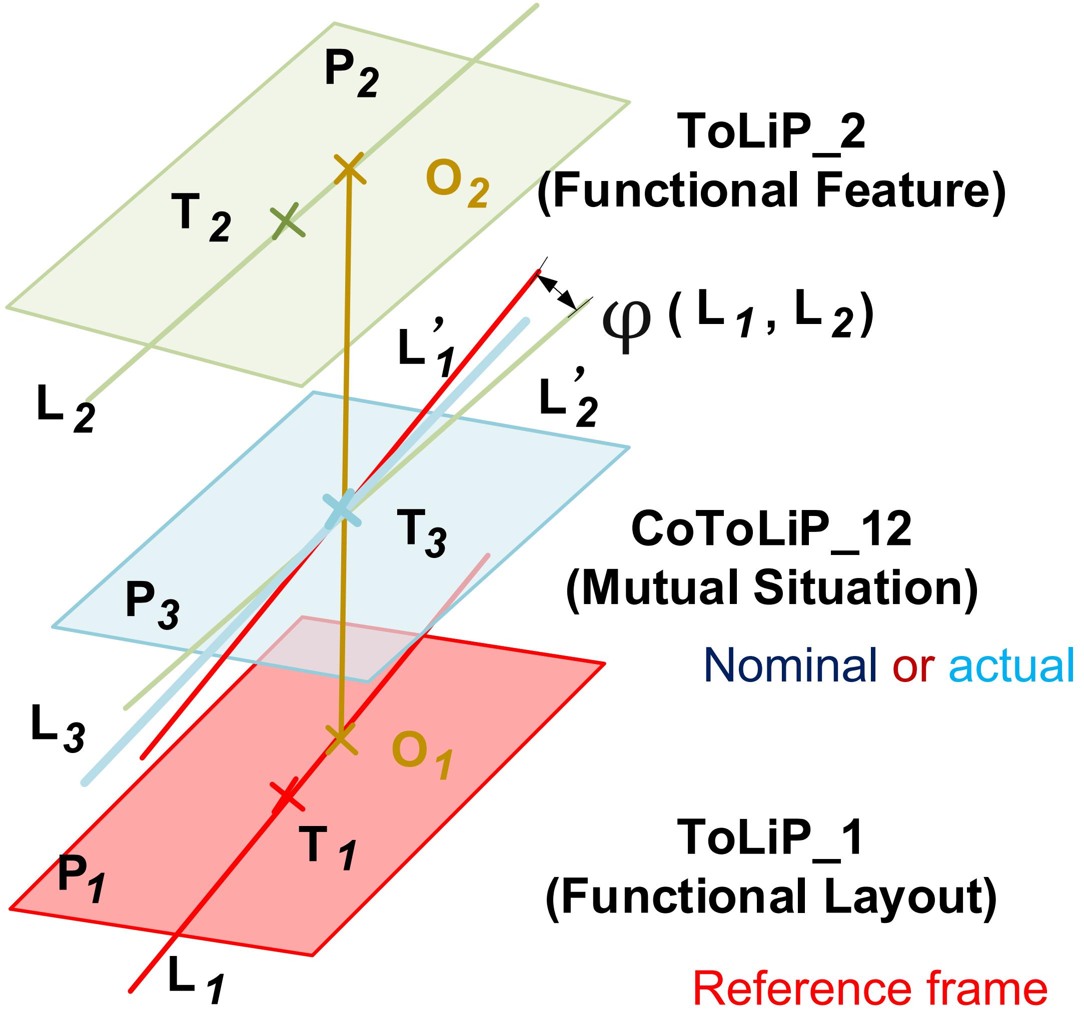




DS_{Si} is a datum system used to define the nominal situation of the equipment along the beam
The situation feature of type [SL] is the magnetic axis: new possibility to address and specify with ISO GPS *non-mechanical features*!
Pending issue: define the restriction of the toleranced situation feature (by default of infinite extension)

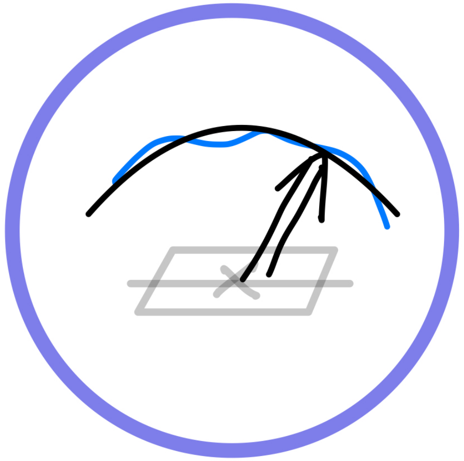
Functional situation: absolute mutual situation

- **Absolute mutual situation: the CoToLiP parameters define the nominal situation of ToLiP 2 with respect to ToLiP1 representing the datum system / reference frame**
- **E.g. here for the coaxiality: d(O1,O2) = 0 and φ =0**
- **No more "cross-talks" between translations: the features defining rotations are always defined**

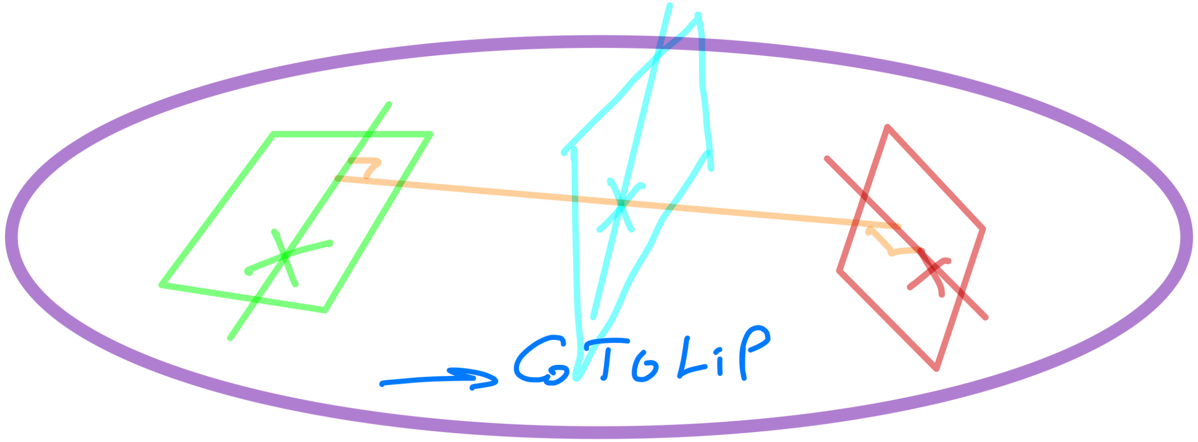


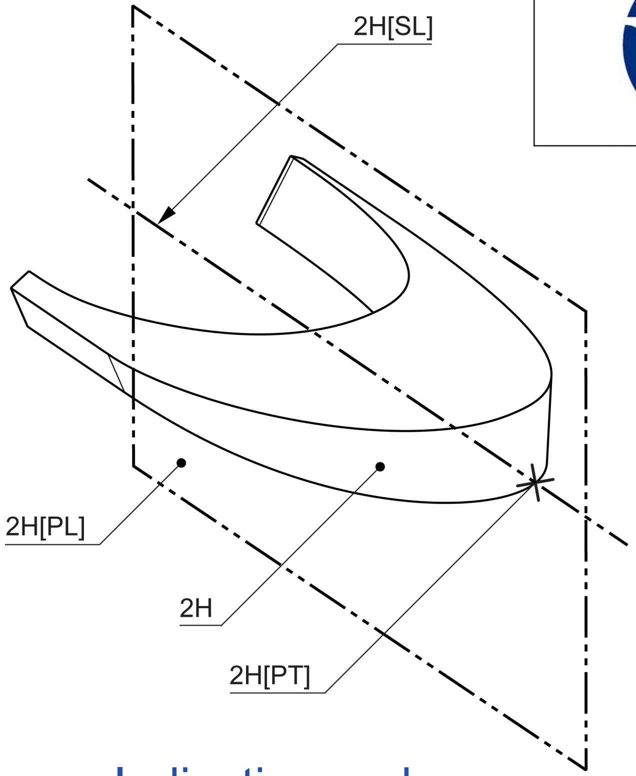
Summary: intrinsic or situational generic characteristics

Intrinsic
(form, shape)

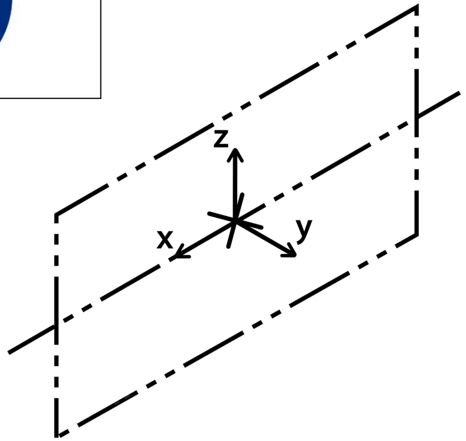


(Mutual) situation
(Location and / or orientation)





Indication and representation of the minimum set of situation features of an integral surface "2H" of invariance class "complex"

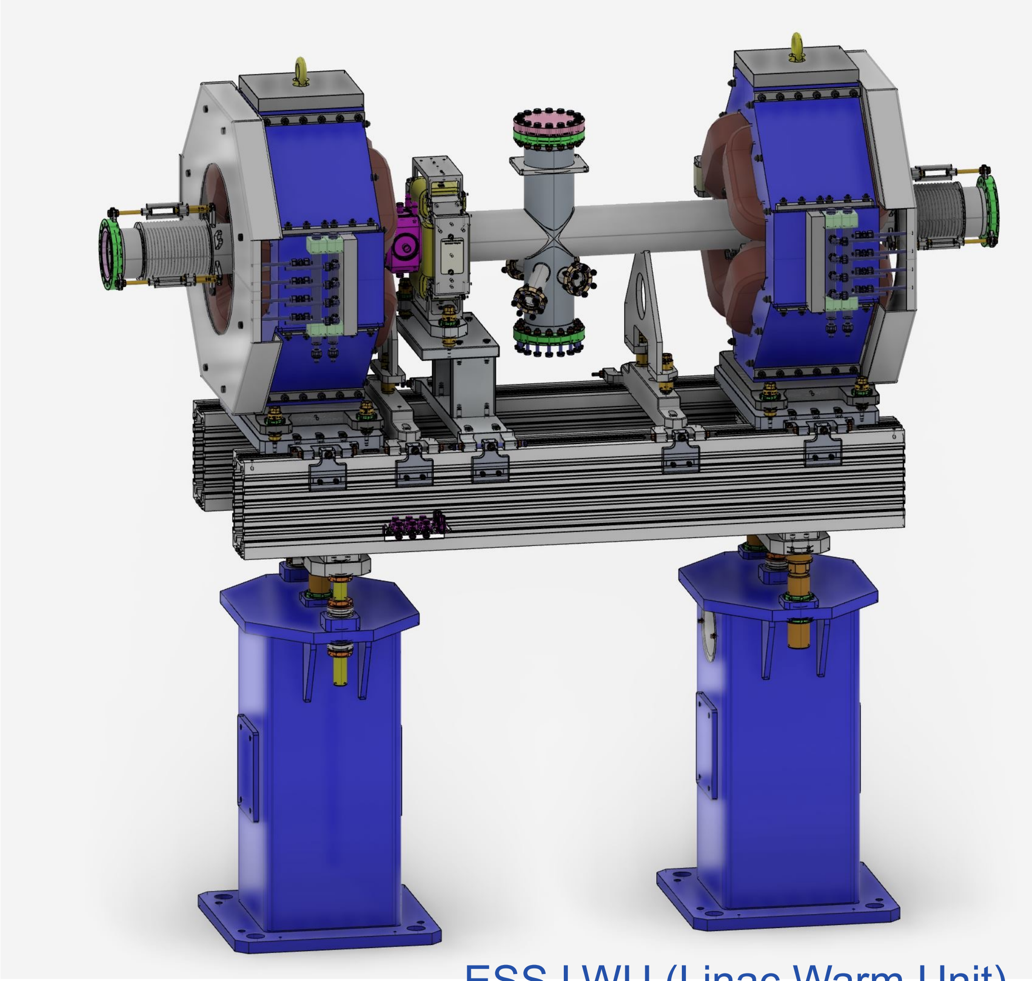


Standardized representation of a coordinate system established on a ToLiP

ISO/DIS 20223:2024

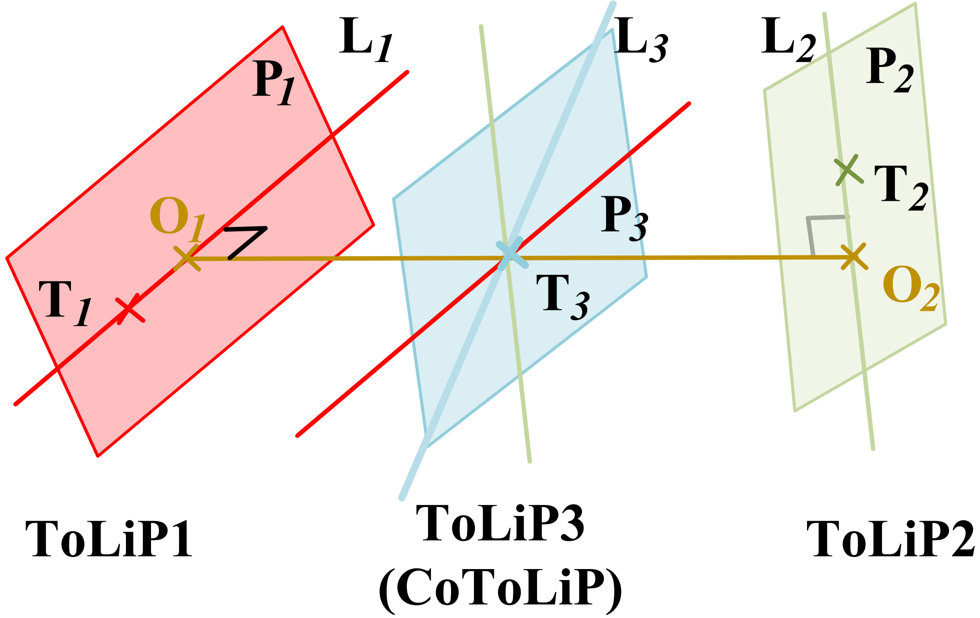
Relative mutual situation: case of two features

- How to characterize the relative mutual situation of two quadrupoles on a raft?



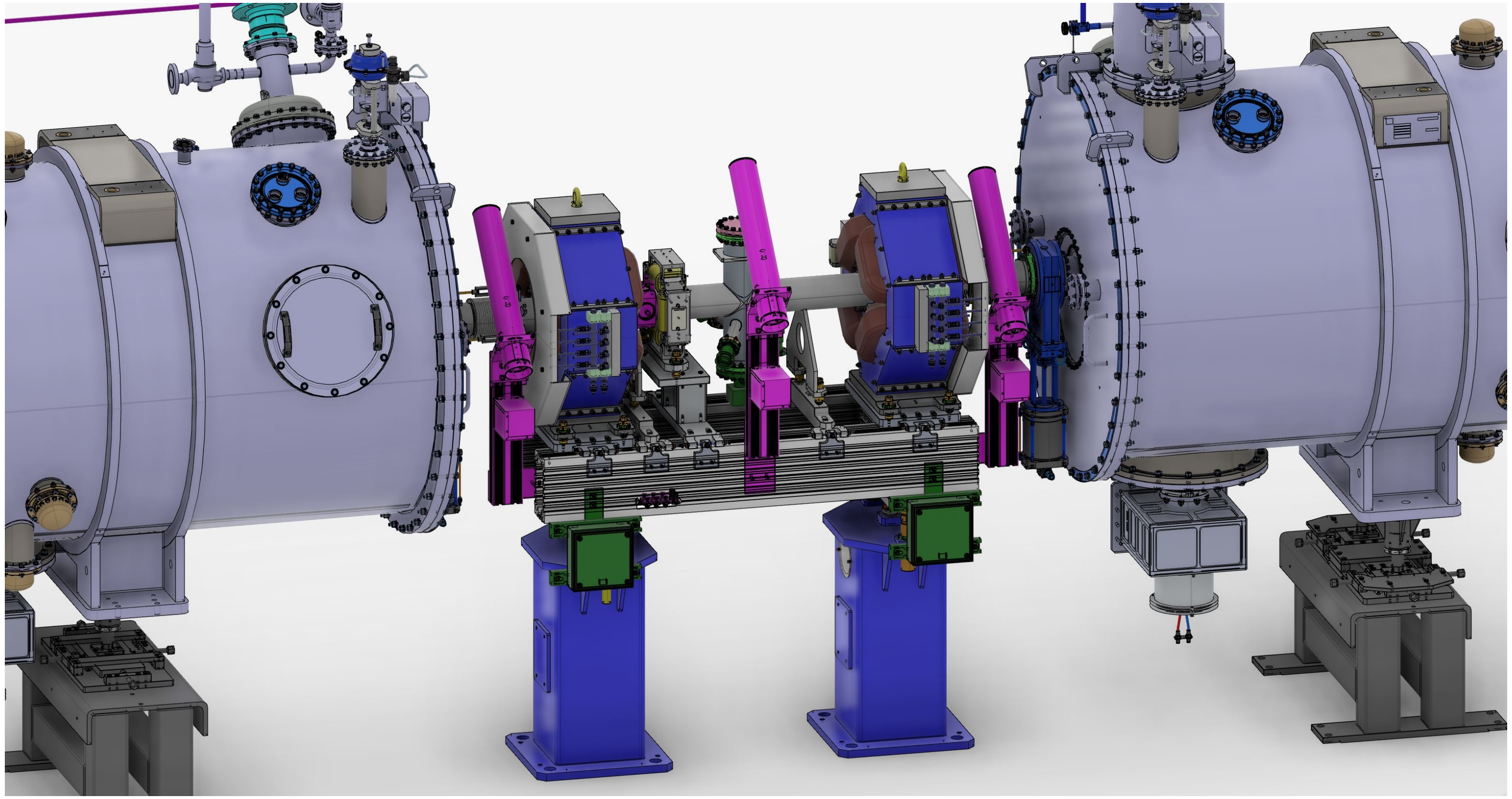
ESS LWU (Linac Warm Unit)

- **With a CoToLiP!**
- Relative = "no one is leading the pair"



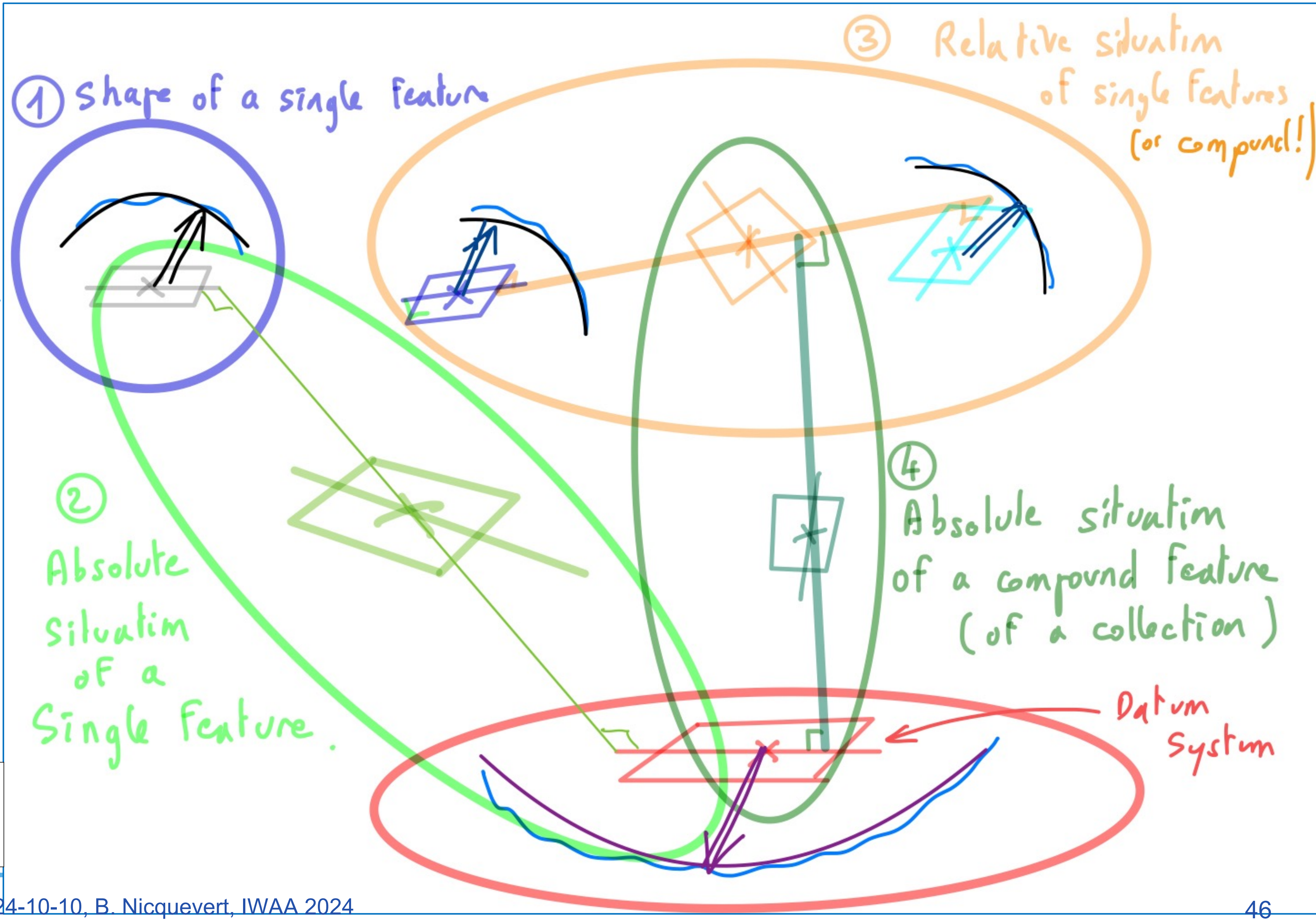
Absolute mutual situation of the collection?

- A LWU (girder) between two cryomodules of the LINAC
- Absolute mutual situation = Position on the lattice
- Same formalism!
- The CoToLiP is a ToLiP!
  - ToLiP3 now represents the whole girder
  - Situation with respect to datum sytem = *absolute* mutual situation



Mutual situation of *two* ToLiPs is handled by CoToLiP

- Allows for handling *relative* mutual situation of a collection of two members
- CoToliP then *represents* the collection of two ToliPs (a CS of collection can be established on it
- CoToLiP handles the *absolute* mutual situation of any collection



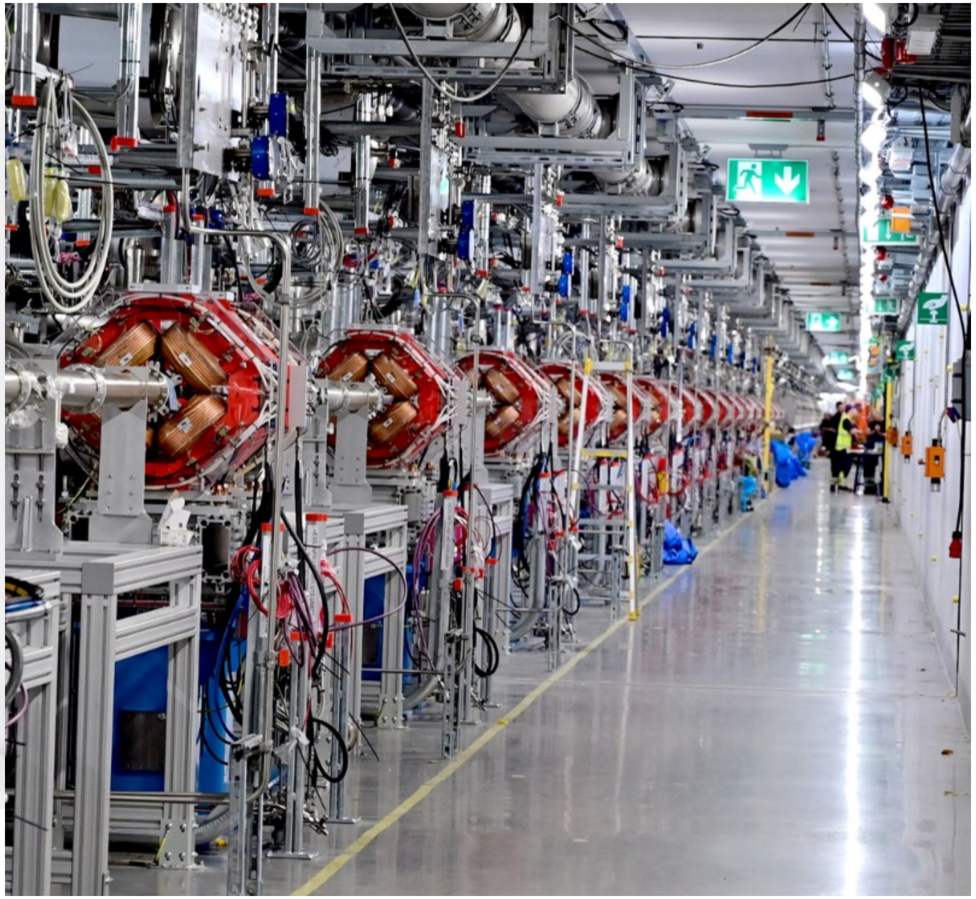
Some perspectives

1. Extension to more than two ToLiPs: **MuToLiP** ✅
2. Extension to contacting features, using **contacting feature** as tolerance feature ✅⚙️
3. Using CoToLiP to evaluate deviations: **CoCoToLiP** ⚙️
4. Developing the rules for using situation features as tolerance features ⚙️
   - Restricted extension, correspondng characteristic, acceptance criteria, …
5. Contributing to ISO GPS tools to encode the specifications per degree of freedom (**Mutual Situation Module**) ✅
6. Integrate this into a roadmap leading to a Global Process to Set Up Geometrical Product Specifications (**GPS² model**) ⚙️

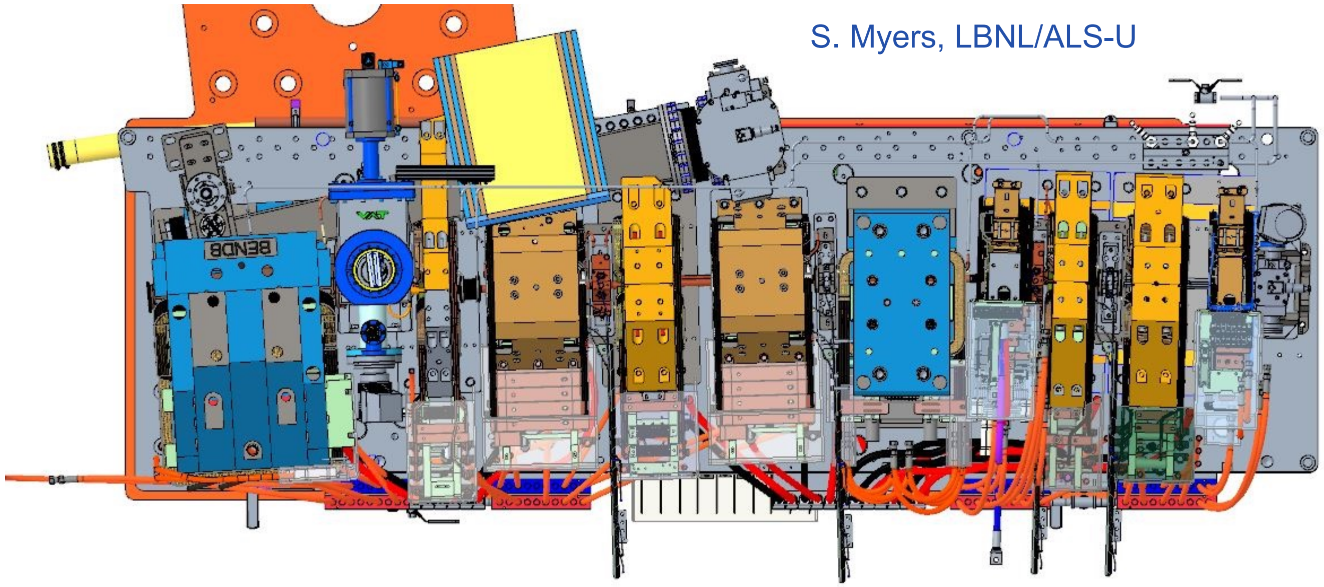
Persp. 1: if the collection is made of more than two members?

- Accelerators (circular or linear) are made of (sometimes many) sectors
- Sectors are made of (sometimes many) rafts / girders (circular or linear)
- Rafts are made of (sometimes many) magnets (with straight or bended axis) and other components

© ESS



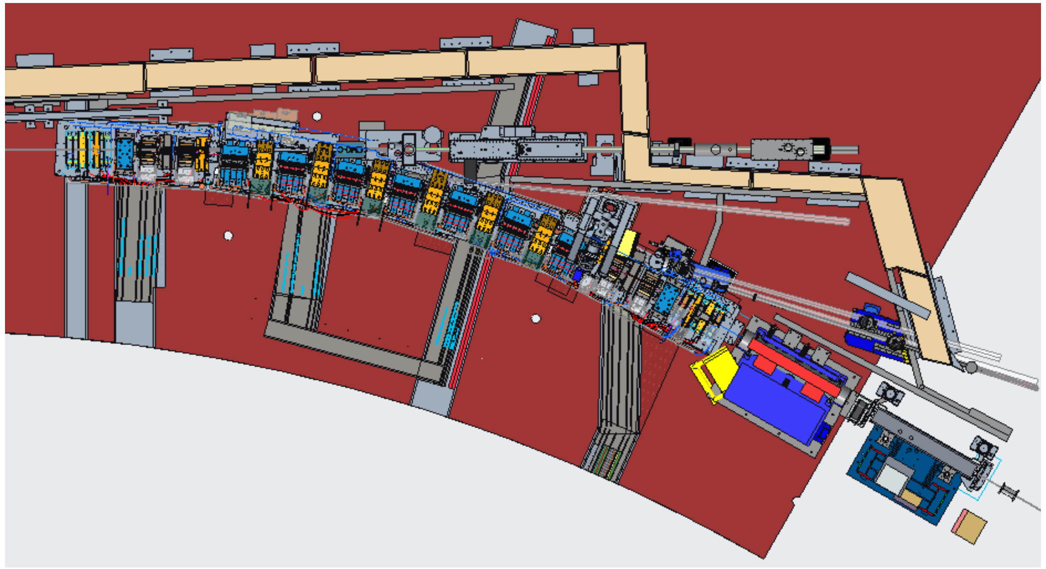
Persp. 1: Another case: ALS-U @ LBNL



S. Myers, LBNL/ALS-U

A raft of type 4: up to 9 magnets of different types
Along a lattice that is bended…

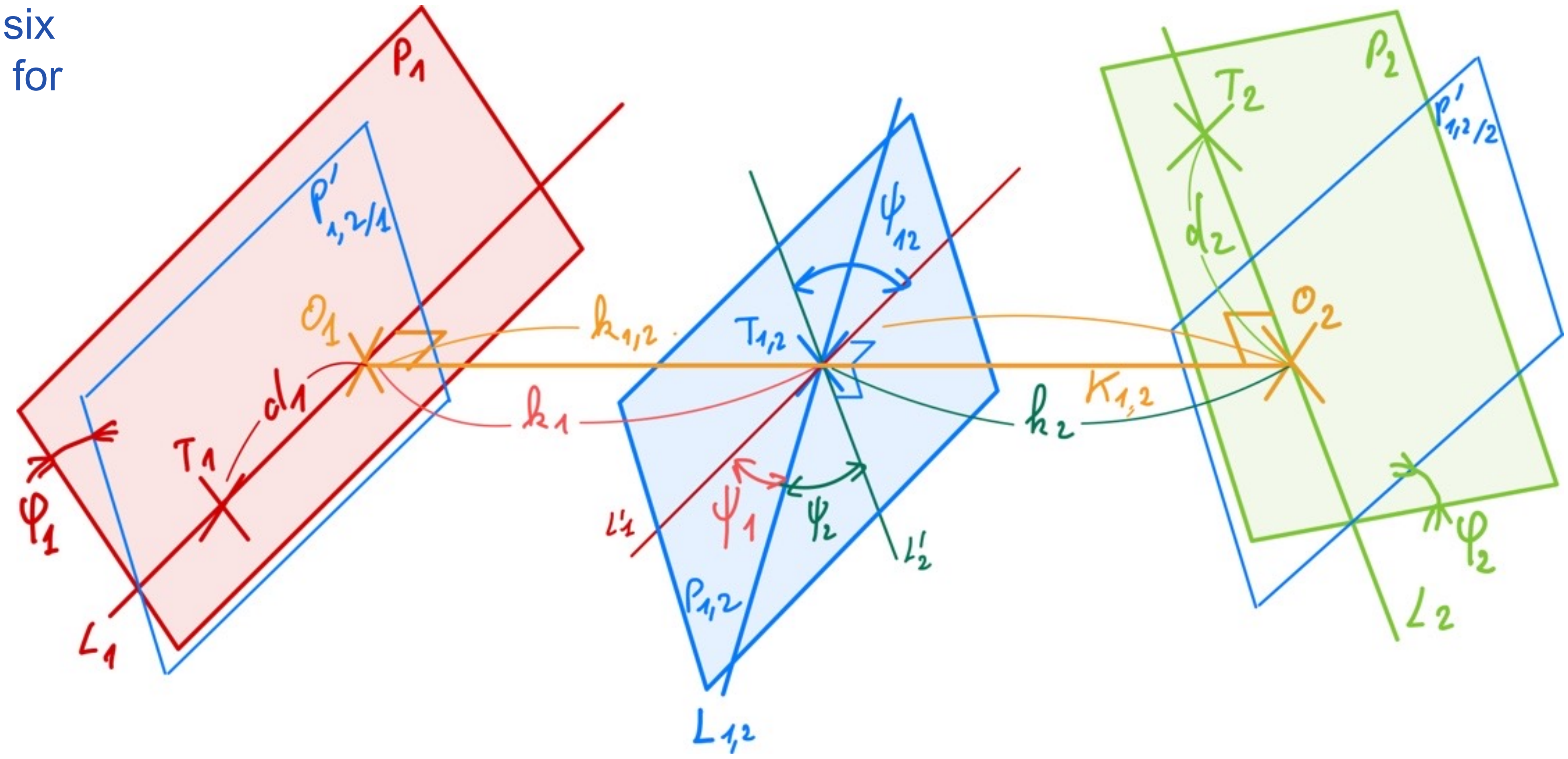
…making up one of the 12 sectors



How to characterize:
Magnet to magnet on a raft? Raft to raft in a sector? Sector to sector in the ring?
What is the "coordinate system"? How is it established?

P1: Mutual situation of *more than two* ToLiPs is handled by *Mu*ToLiP

The CoToLiP with its six parameters prepared for our next phase: generalized to **MuToLiP**

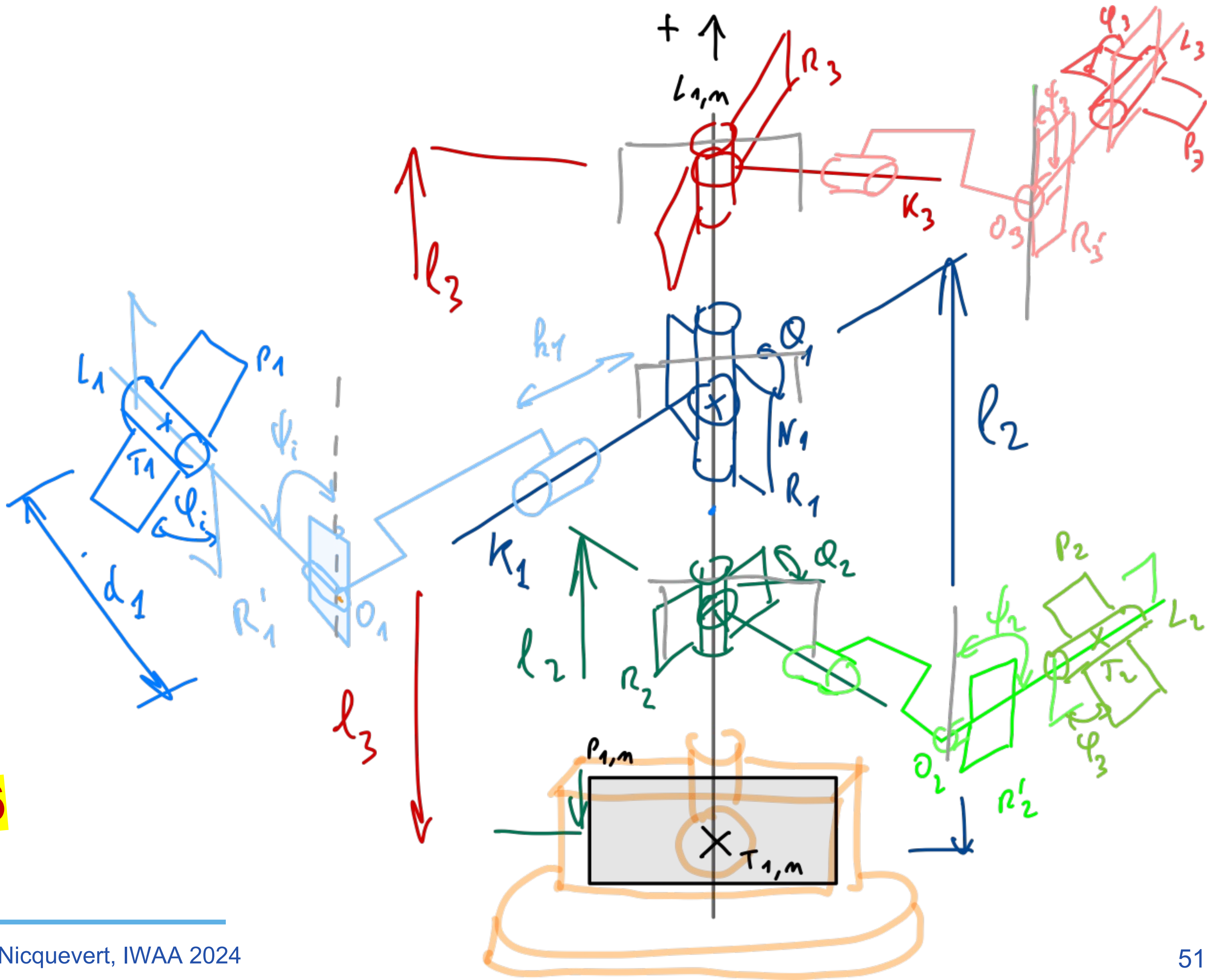


For IWAA 2026

MuToLiP (**mu**ltiple **to**… composition): operator for the parametrisation of the mutual situation of *any* number of ToLiPs, *n*≥2

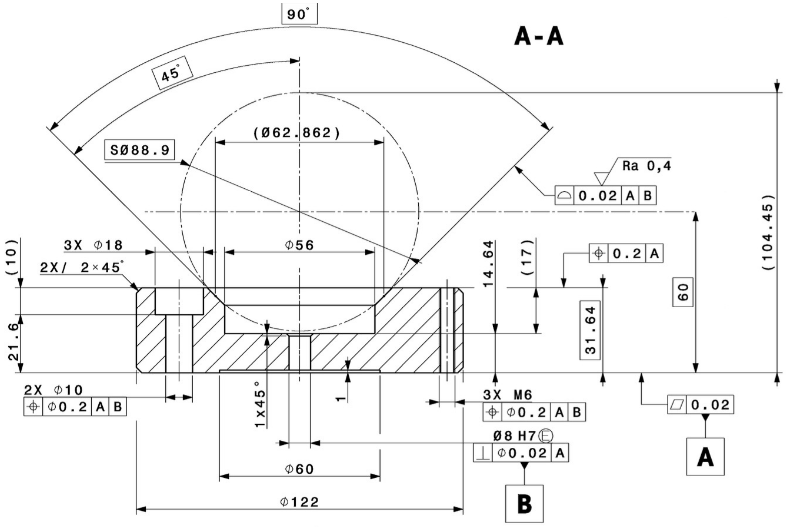
Useful to establish the ToLiP of any **constellation** of spheres

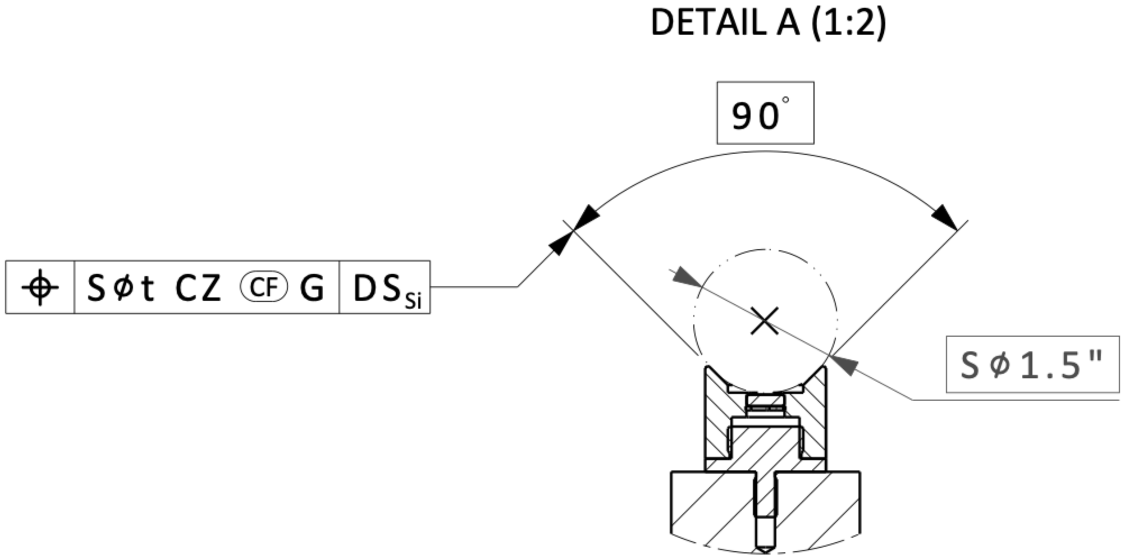
For IWAA 2026



Perspective 2: contacting features

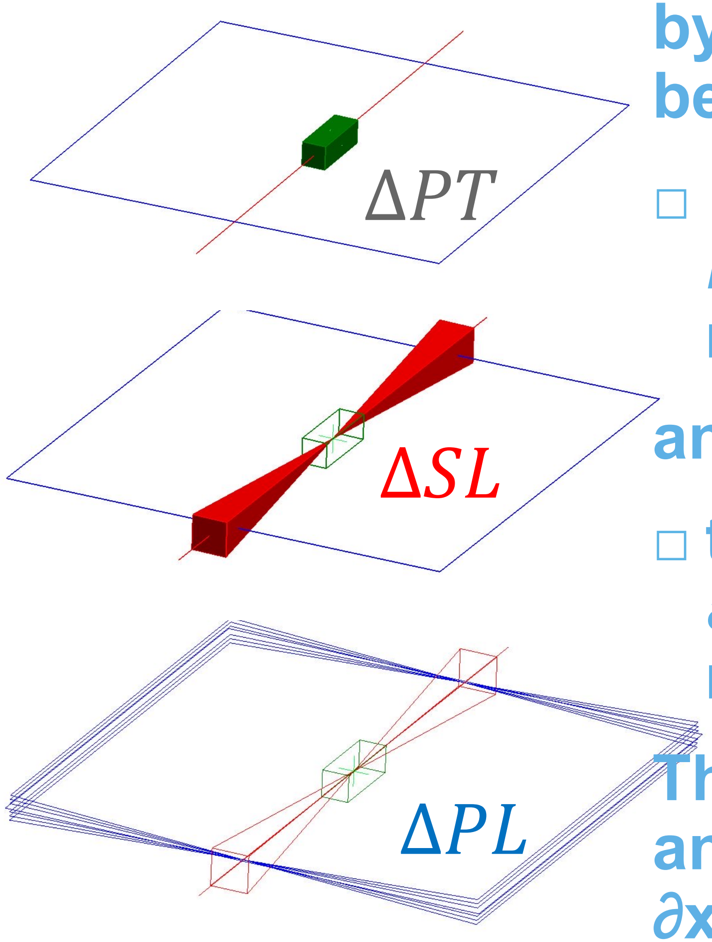
- *Extension of invariance classes* to include contacting features [CF] ⚙️ 🌶️🌶️🌶️
  - **Features that are technologically but NOT topologically related (i.e. of a different types than the integral features they are associated w ith)**
  - **Situation features of the CoToLiP in these cases may have intrinsic mobilities extending beyond the TTRS cases**
- Using contacting feature as tolerance feature ✅





Perspective 3: handling deviations

From IWAA2022



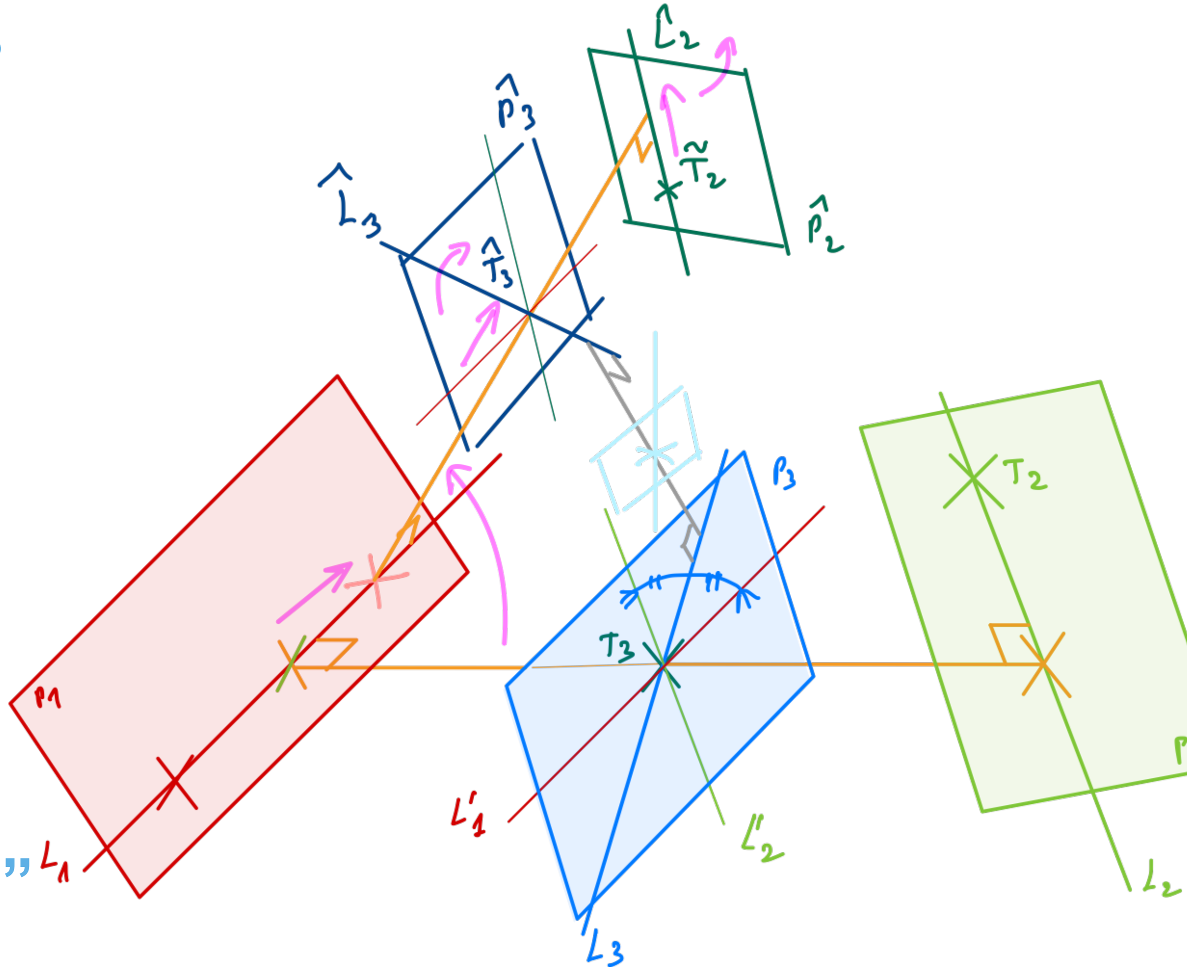
Assess the deviations? by using the CoToLiP between:

- □ **the CoToLip of *nominal* absolute mutual situation**

and

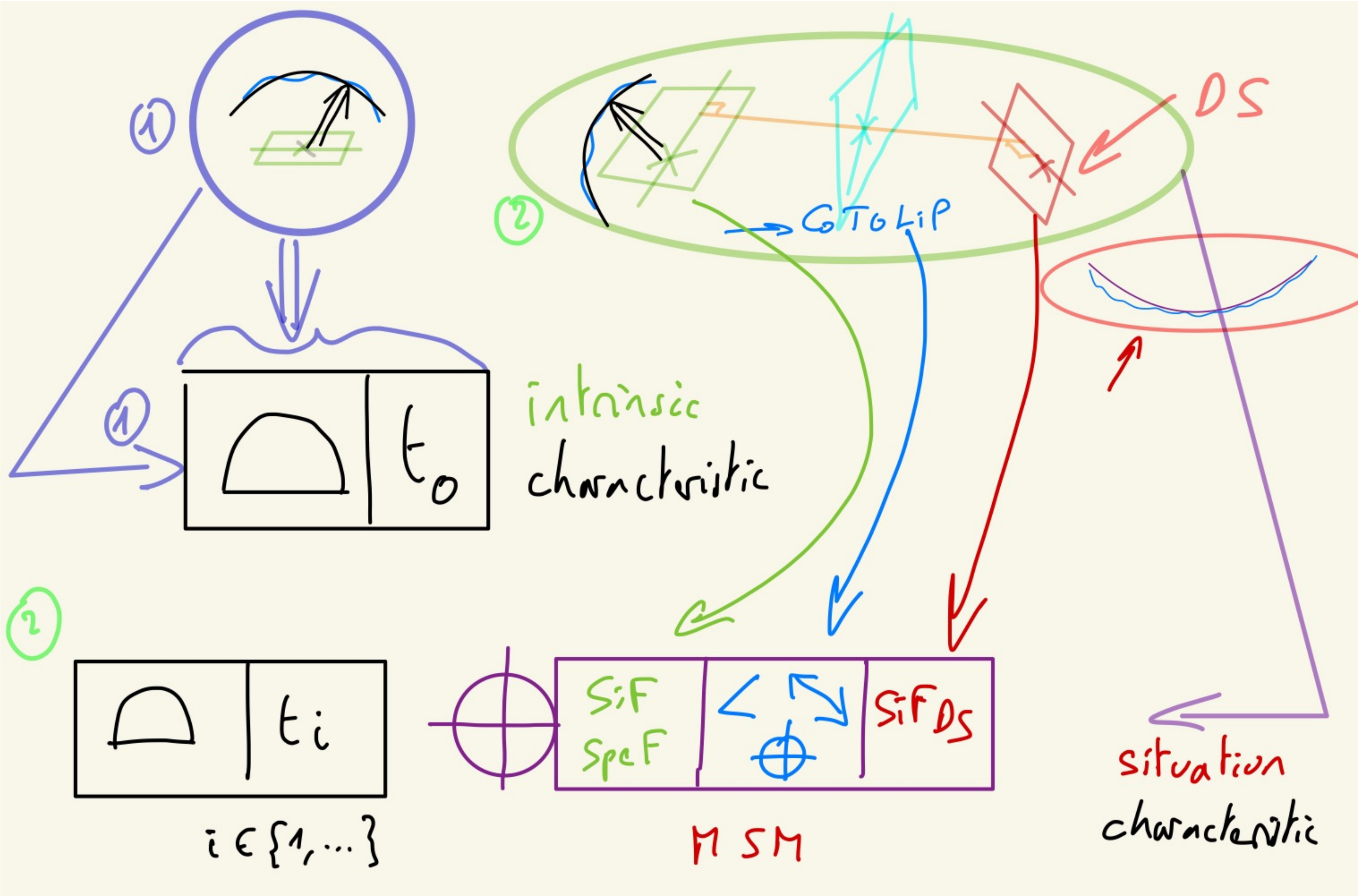
- □ **the CoToLiP of the *actual* absolute mutual situation**

This is the "CoCoToLiP" and its six parameters ∂x, ∂y, ∂z, ∂u, ∂v, ∂w



For IWAA 2026

Perspectives 4 and 5: GPS standard of mutual situation ✅



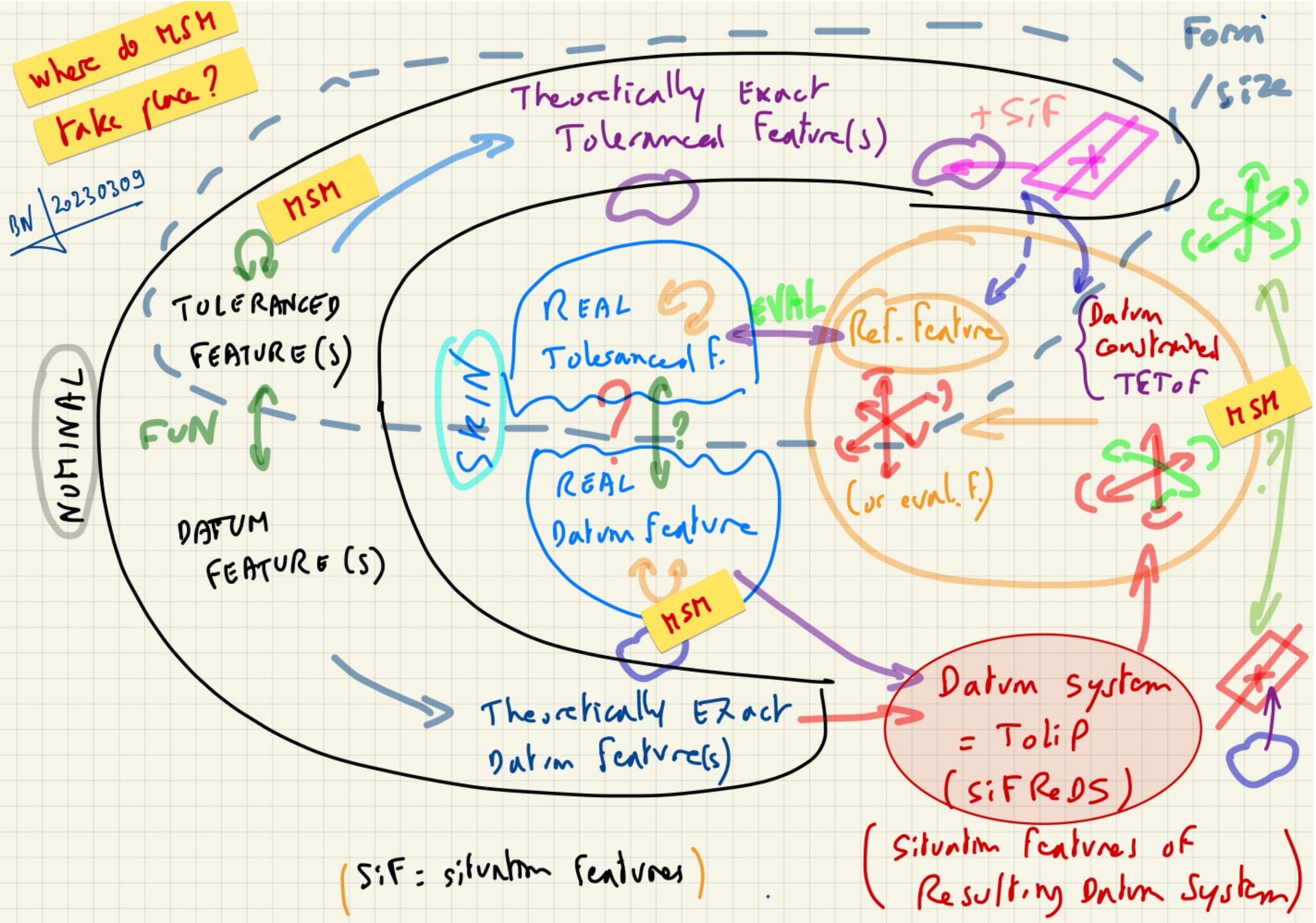
- MSM (Mutual Situation Module) is proposed to indicate ***explicit individual constraints*** **between situation features into an ISO GPS** ***specification frame***
- **DS: Datum System**
- **SiF: Situation feature set**
- **⌓: Surface profile**

NEW project ISO/PWI 25431

Perspective 6: GPS²

***Challenge*: assess the conformity of a real part (in blue) with respect to the specifications (in green) defined in the nominal model (in black)**
Overall map model v 1.2
Model v. 2.5 is available

More in “For a Global Process to Set a Geometrical Product Specification [GPS^2]: a R&D Roadmap Toward an Extensive and Extended Use of Situation features in ISO Geometrical Product Specification (GPS) Standards.”



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