# ILC Coordinate Reference System

## Or: how to do Design Integration for a 30km long building

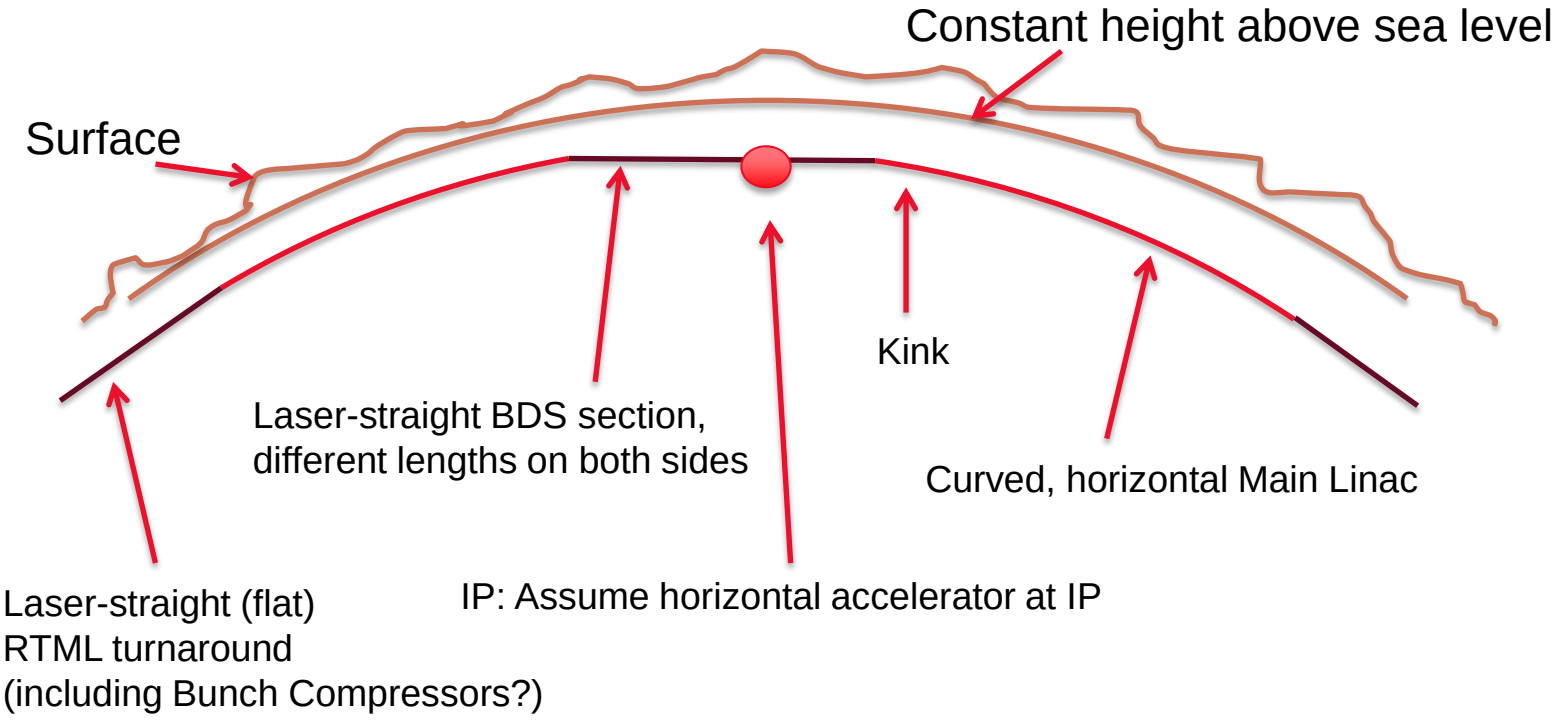
Benno List

DESY

LINEAR COLLIDER COLLABORATION

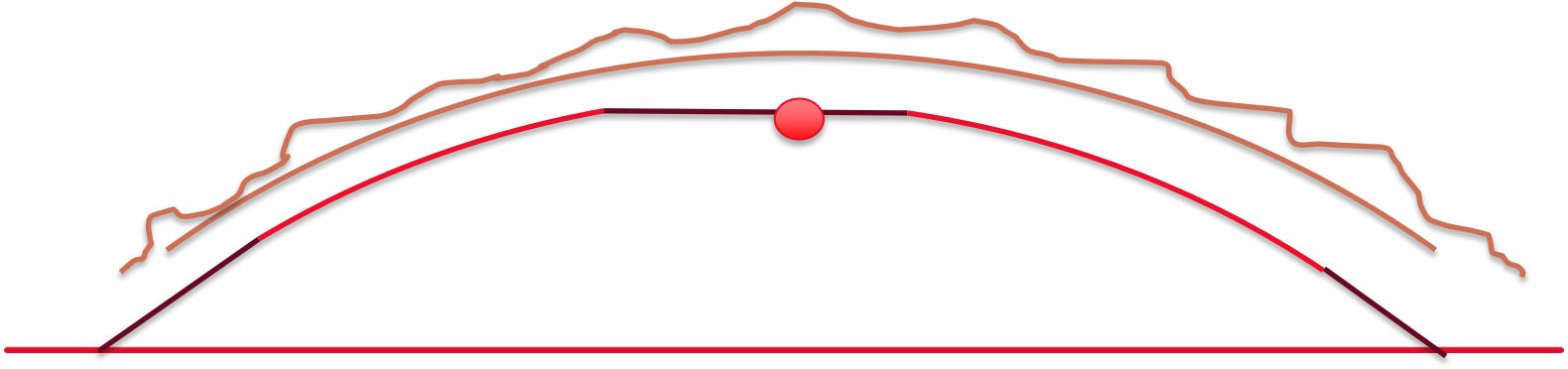
Designing the world's next great particle accelerator

# Schematic ILC Side View



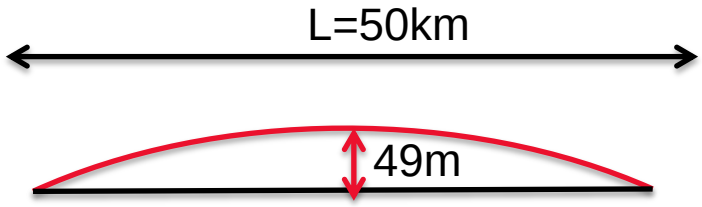
# The Problem: How to model a 30km long building

- The earth's surface is curved
- "Up" is a different direction everywhere on earth
- A horizontal "straight" tunnel is curved in reality
- GIS systems understand this
- CAD systems do not understand this!



# Size of curvature for ILC

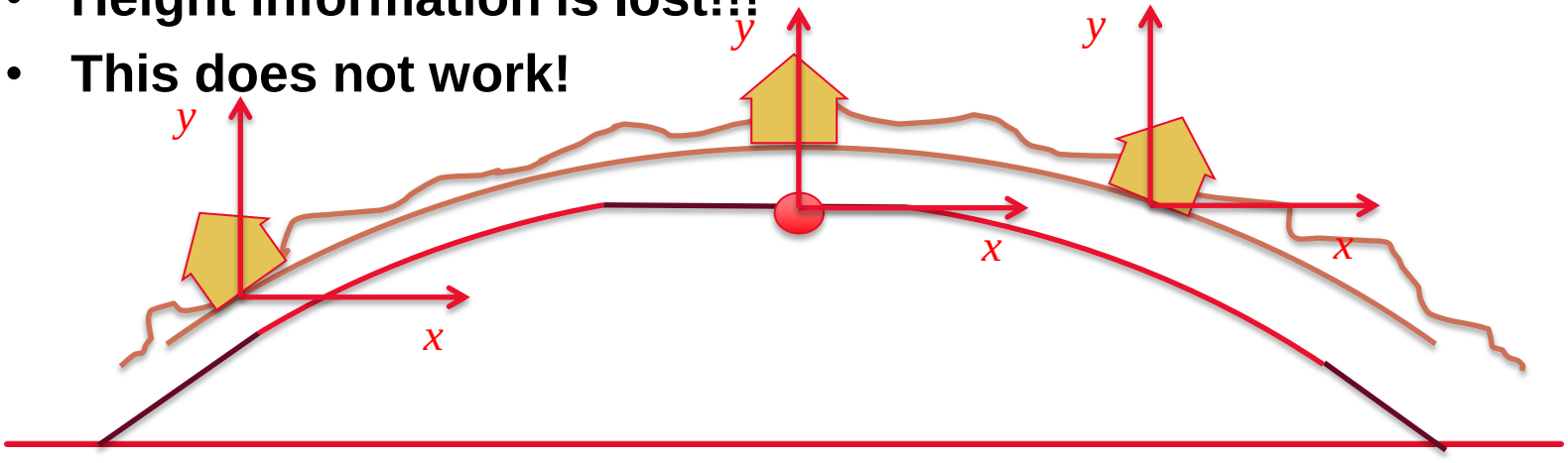
- **Over a length of L= 50km, earth curvature corresponds to a sagitta of $L^2/(8R_E)$ = 49m**
  **30km->18m; 10km->2m; 5km->0.5m**




- **For accurate planning of shaft geometry (depth, length, slope) a definition is needed which parts of the machine (if any!) follow the earth's curvature and which ones are laser-straight**
- **My understanding:**
  - Main Linac sections follow earth's curvature
  - Central region (undulator section and BDS) are laser-straight (means that tunnel floor is slightly sloped in central region, and kink between ML and central region);
    main reason: helium lines should not be sloped
  - Damping rungs are flat (do not follow earth curvature) -> negligible effect
  - RTML turnaround sections (the "ears") are laser straight (small effect).
- **At some point, we need to write a formal document that specifies this**

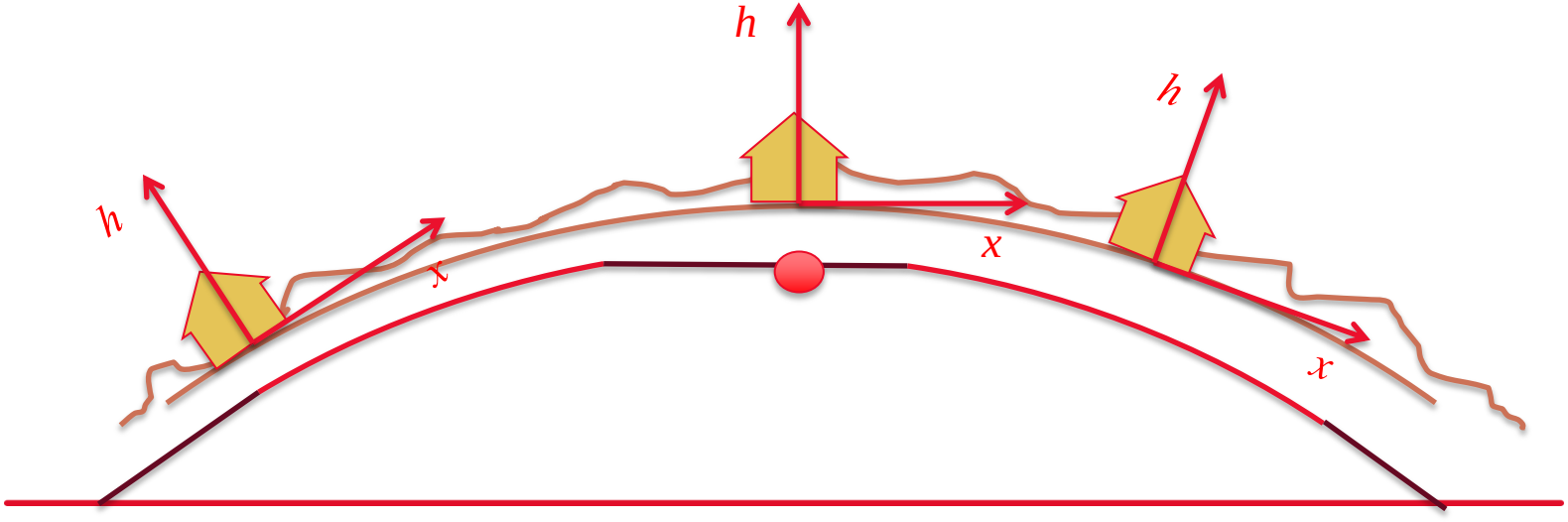
# The naïve approach: not a solution!

- Use a orthogonal coordinate system pinned to one point of the earth
- Upright buildings will be inclined
- Horizontal tunnels will be curved
- Height information is lost!!!
- This does not work!



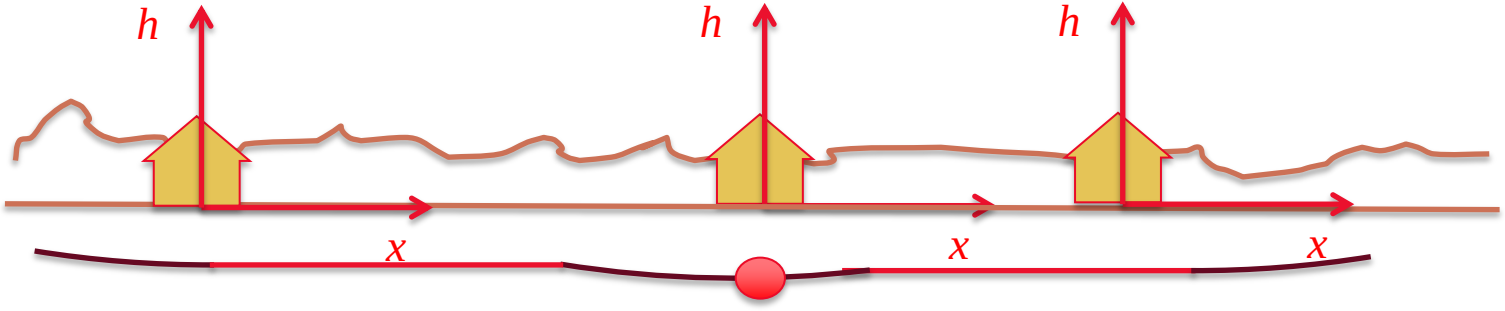
# The real solution

- Use coordinates that are locally orthogonal
- One axis is height: always points “up” everywhere
- The other axes are orthogonal



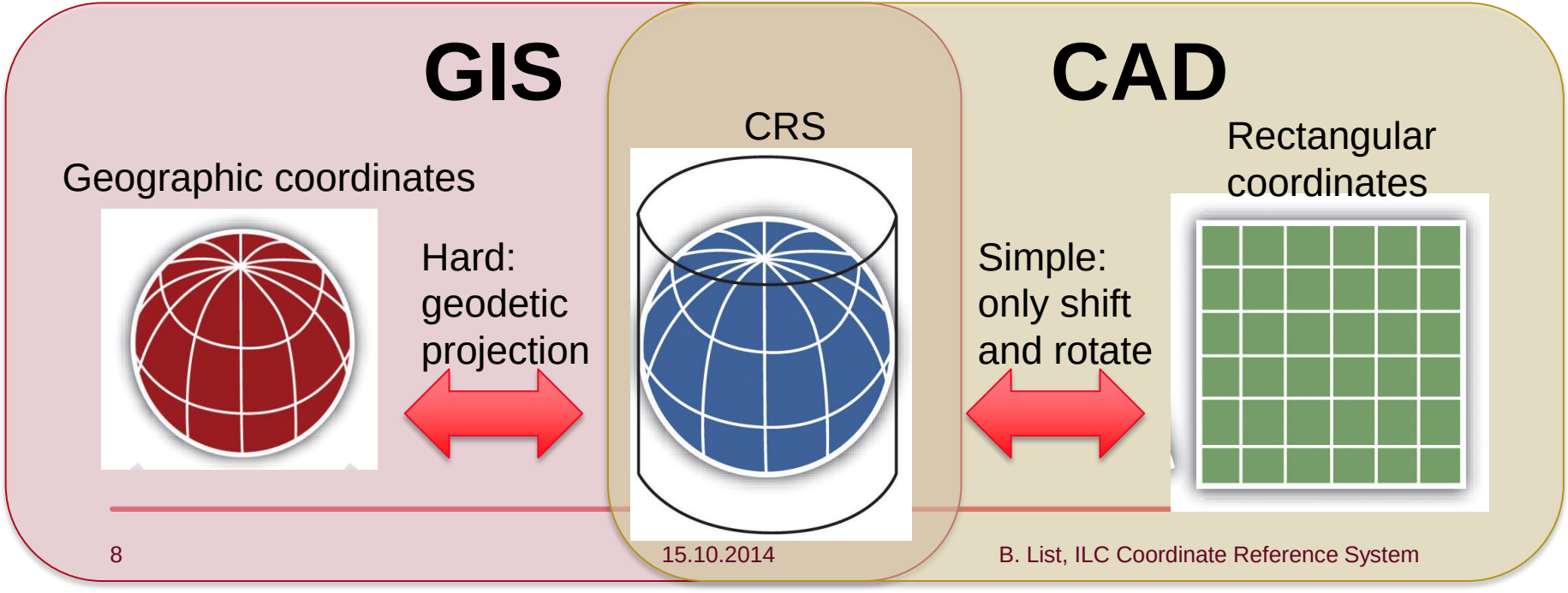
# The real solution: A projection

- Use coordinates that are locally orthogonal
- One axis is height: always points “up” everywhere
- The other axes are orthogonal
- All buildings are “upright”
- Horizontal tunnels are straight
- But: laser-straight tunnels are curved!



# The role of the Coordinate Reference System

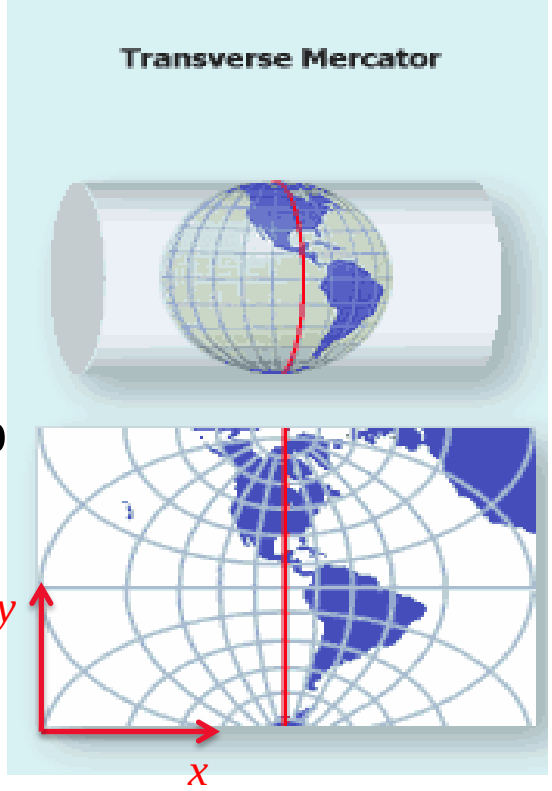
- **CRS is a locally orthogonal system, into/from which coordinates from GIS and CAD systems can be transformed**



# Coordinate Reference Systems

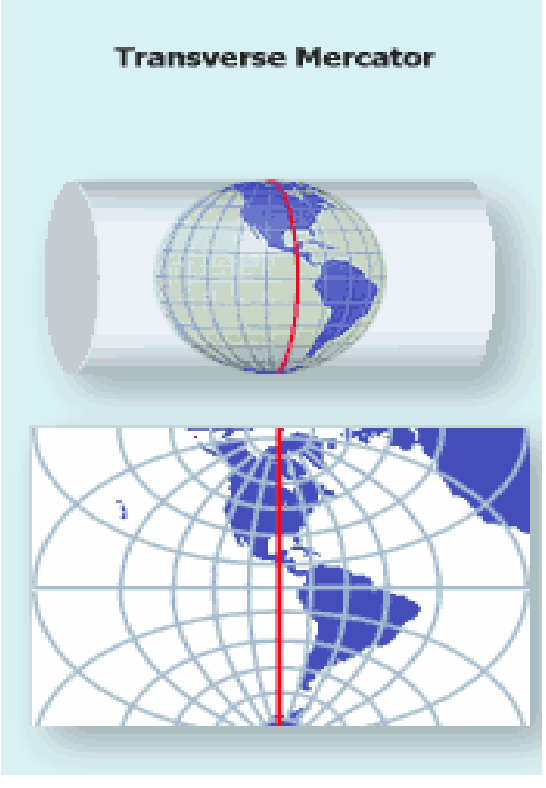
**A Coordinate Reference System consists of**

- **A geodetic datum: Parameter set of the earth's shape, plus definition of a reference meridian**
- **A projection: Relates longitude/latitude(+height) to x/y (+z) coordinates suitable for plotting on a map**
- **A CRS defines a coordinate grid on the earth's surface**



# Requirements for ILC CRS

- Minimal scale distortions in the interesting region: Main Linac tunnels and a few km to the side
- Projection should conserve angles (circles on surface are circles on the map, small rectangles stay rectangles)
  -> “conformal” projection
- Solution: Use a Mercator projection (conformal), with a center line following roughly the Kitakami site strip
- -> This is a “oblique” Mercator projection



# Formal Definition

- Datum:
  Japanese geodetic Datum 2000 (JGD2000)
  as used for Japanese topographic maps
- Vertical Datum: GSIGEO2011
- Center point and middle line:
  $\lambda_C$=141.39° , $\varphi_C$=39.03° , $\alpha_0$=-20.2°
  -> close to planned IP, but not exactly
  -> does not divulge IP location
- Center Point gets offset values
  $x_0$=5000m, $y_0$=50000m
  so all coordinate values are positive

The Geographic Coordinate Reference System ILC CRS 2014

Benno List, DESY, and Tomoyuki Sanuki, Tohoku University and KEK

Introduction

The overall length of the ILC is so big that the earth curvature needs to be taken into account in the design of the accelerator. The longest sections of the ILC, the two arms of the Main Linac, with a length of about 10.5km each in the baseline configuration, will follow the curvature of the earth so that the cryomodules can be mounted horizontally and the liquid helium inside them does not flow to one side.
The sagitta for a 30km long tunnel that follows the earth curvature is 18m, for a 50km long tunnel it amounts to 49m. Thus, in a global 3D CAD model or lattice this effect is non-negligible.

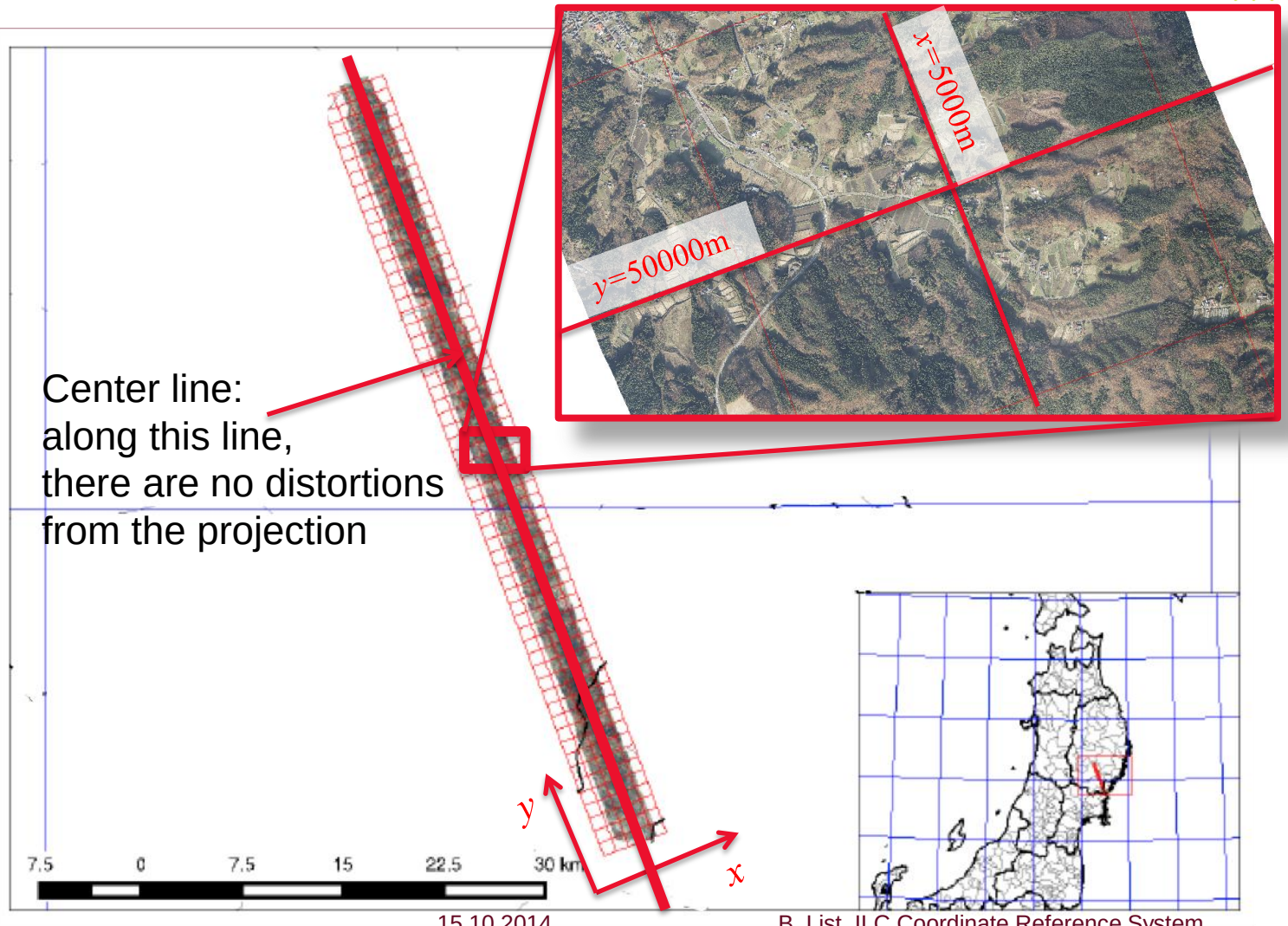
A natural, but somewhat naïve, approach to the handling the earth curvature would be to work in an orthonormal coordinate system, with origin at the Interaction Point, y pointing upwards at the IP, z pointing along the "mean" axis of the Main Linac in the electron flight direction, and x being perpendicular to x and z to form a right-handed orthonormal coordinate system.
In such a system, the Main Linac tunnels, and the Main Linac lattice, would be sloped considerably, and the y coordinate of the beams in the Main Linac would deviate considerably (by up to 18 m) from 0 for an earth-curvature following linac.

The ILC lattice approaches this problem in a different way: Implicitly, it treats the y coordinate (in the Main Linac region) as corresponding to the local vertical direction, so that the earth curvature following beam has a constant y value of 0. The necessary bending, and the dispersion introduced by that bending, is accounted for by applying "vertical kicks" to the beam at the locations of the corrector magnets, and using the correctors to "steer out" these kicks, so that the beam stays at y=0.
If such a lattice is to be overlaid with a 3D tunnel model this means that the tunnel has to be constructed with the same convention, i.e., a "straight" tunnel following the earth's curvature has to follow a straight line in the CAD system, while in truth it follows a great circle (or the equivalent on the oblate ellipsoid of the earth).

Now, the transformation from the curved surface of the earth, which is described by latitude φ, longitude λ, and height h (above sea level), to a "flat" surface with coordinates x and z in the plane and y for the height is exactly what a map projection does.
Or, turning the point of view around: A map projection defines a mapping between coordinates (φ, λ, h) and (x, y, z), where typically hey. Thus, (x, y, z) form a curvilinear coordinate system, in which a (laser-)straight line is not straight anymore. In tensor calculus, such a coordinate system would come with a metric tensor that is not the identity anymore.

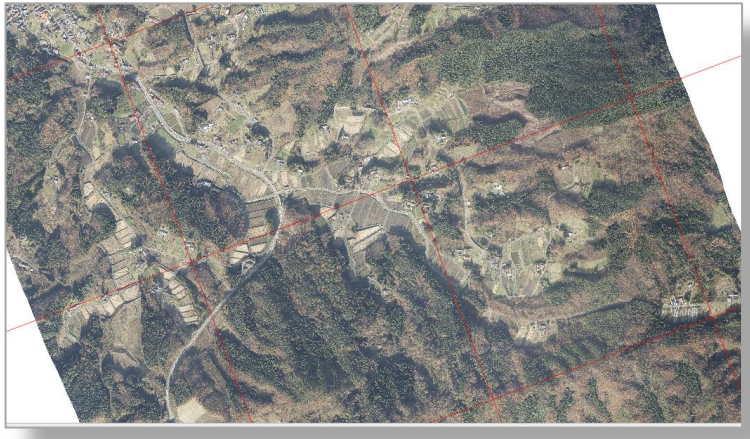
EDMS: D*1084525

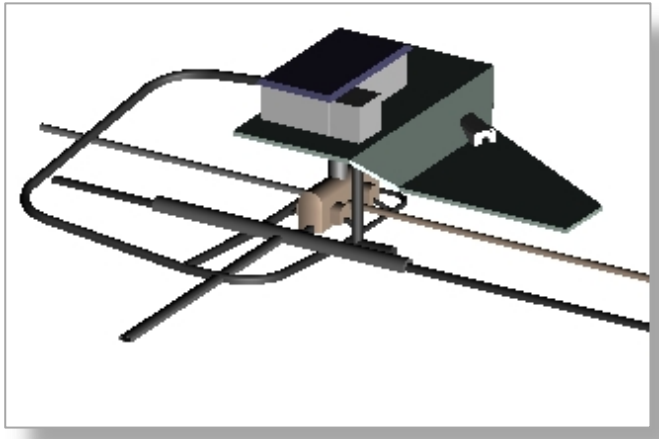
# ILC CRS Overview



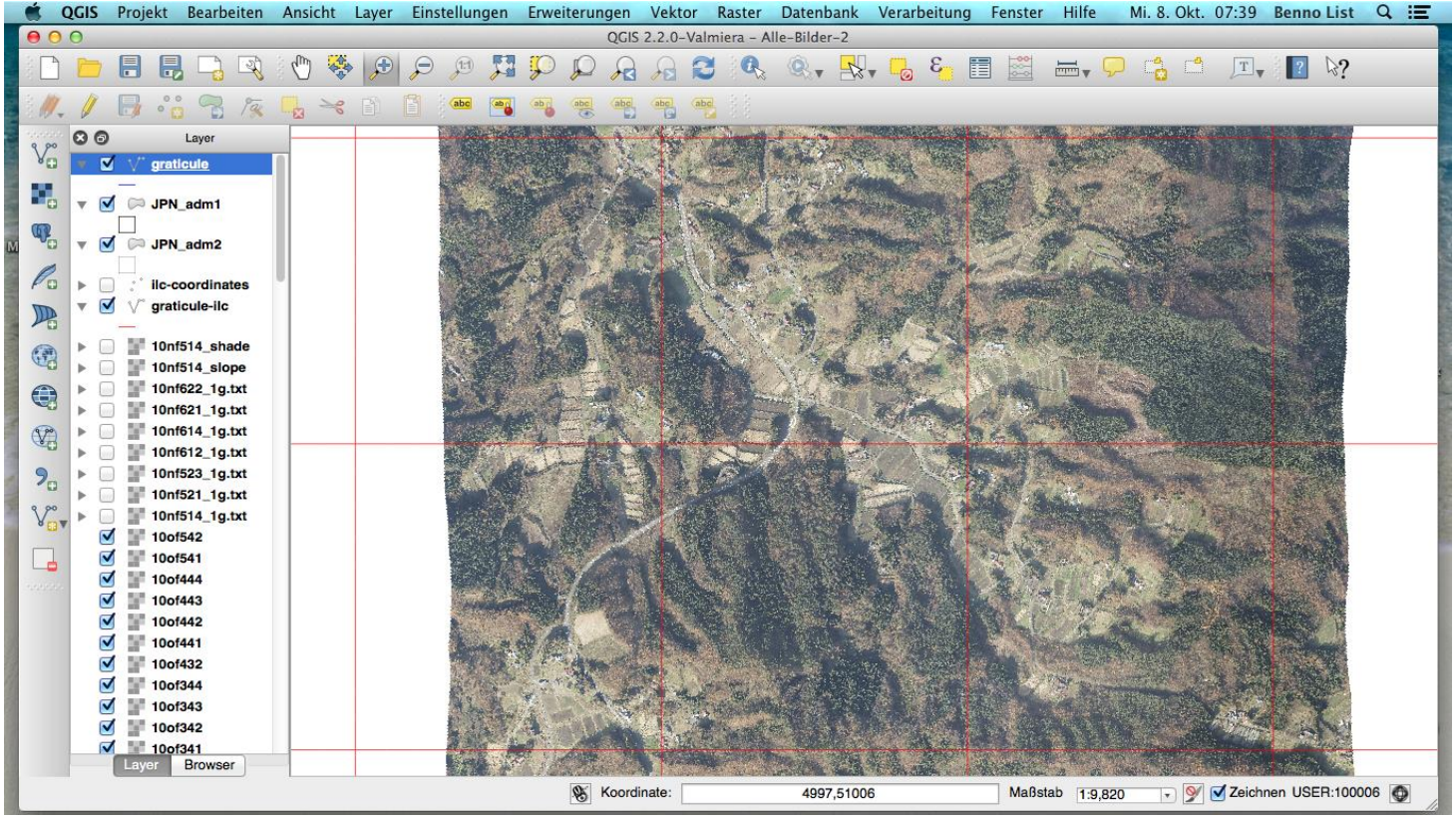
# Application

- **ILC CRS allows to bring together**
  - Geographic data: Elevation models, Aerial images, Map data
  - CAD data: Buildings, tunnels, shafts
- **Combination of data can be done**
  - In Geographic Information System: GIS
  - In CAD system

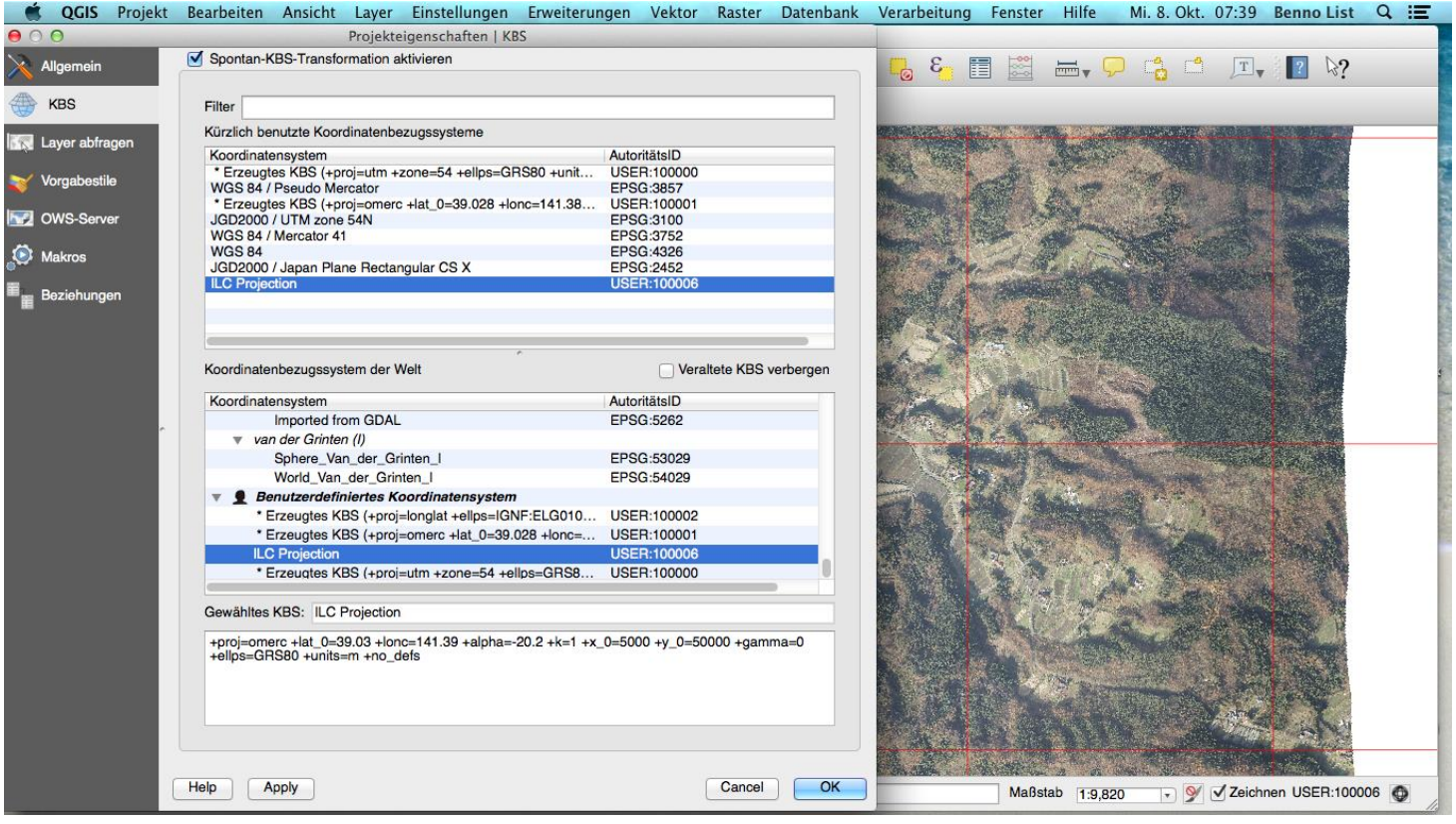




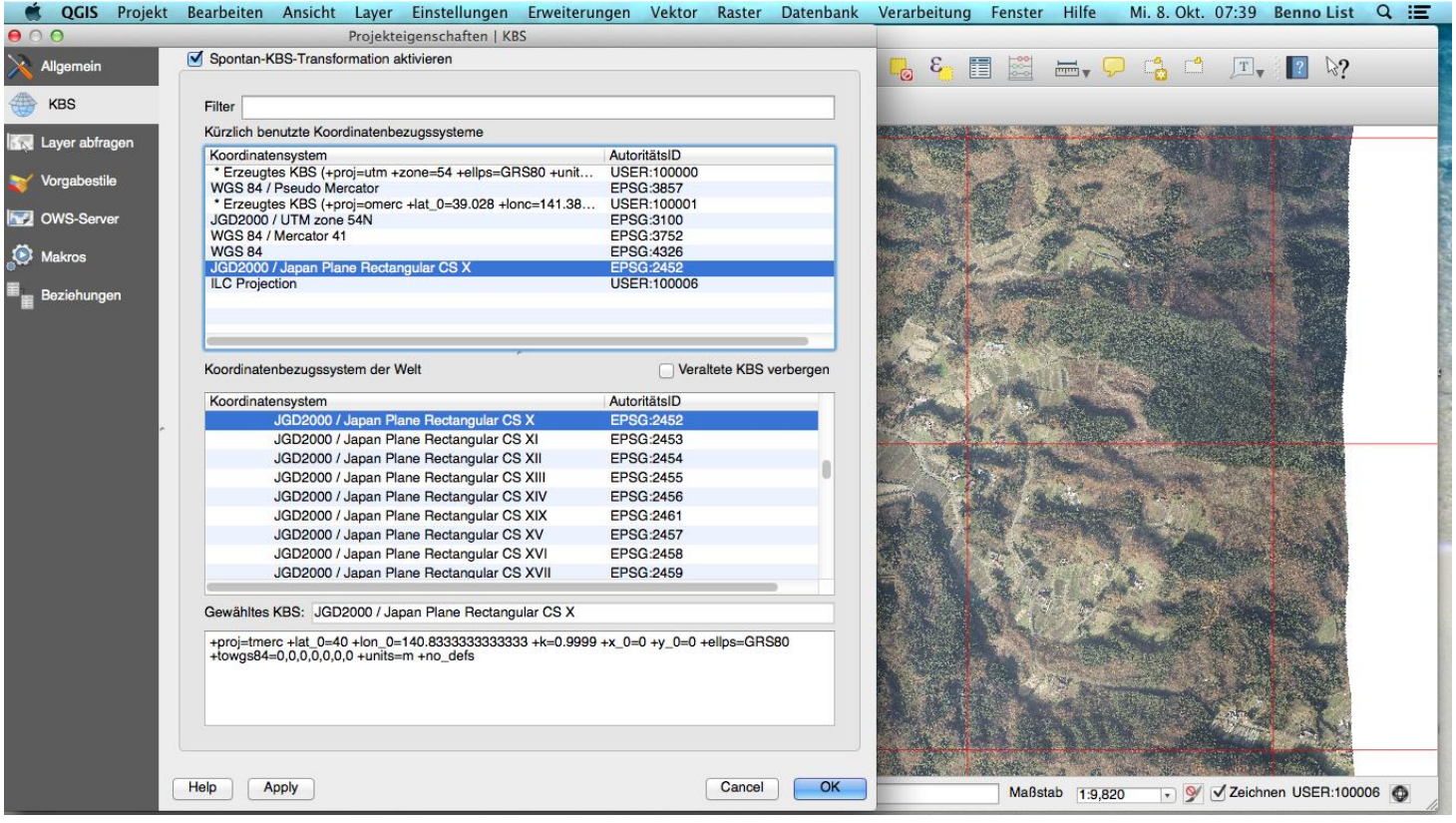
# Using a CRS in a GIS system



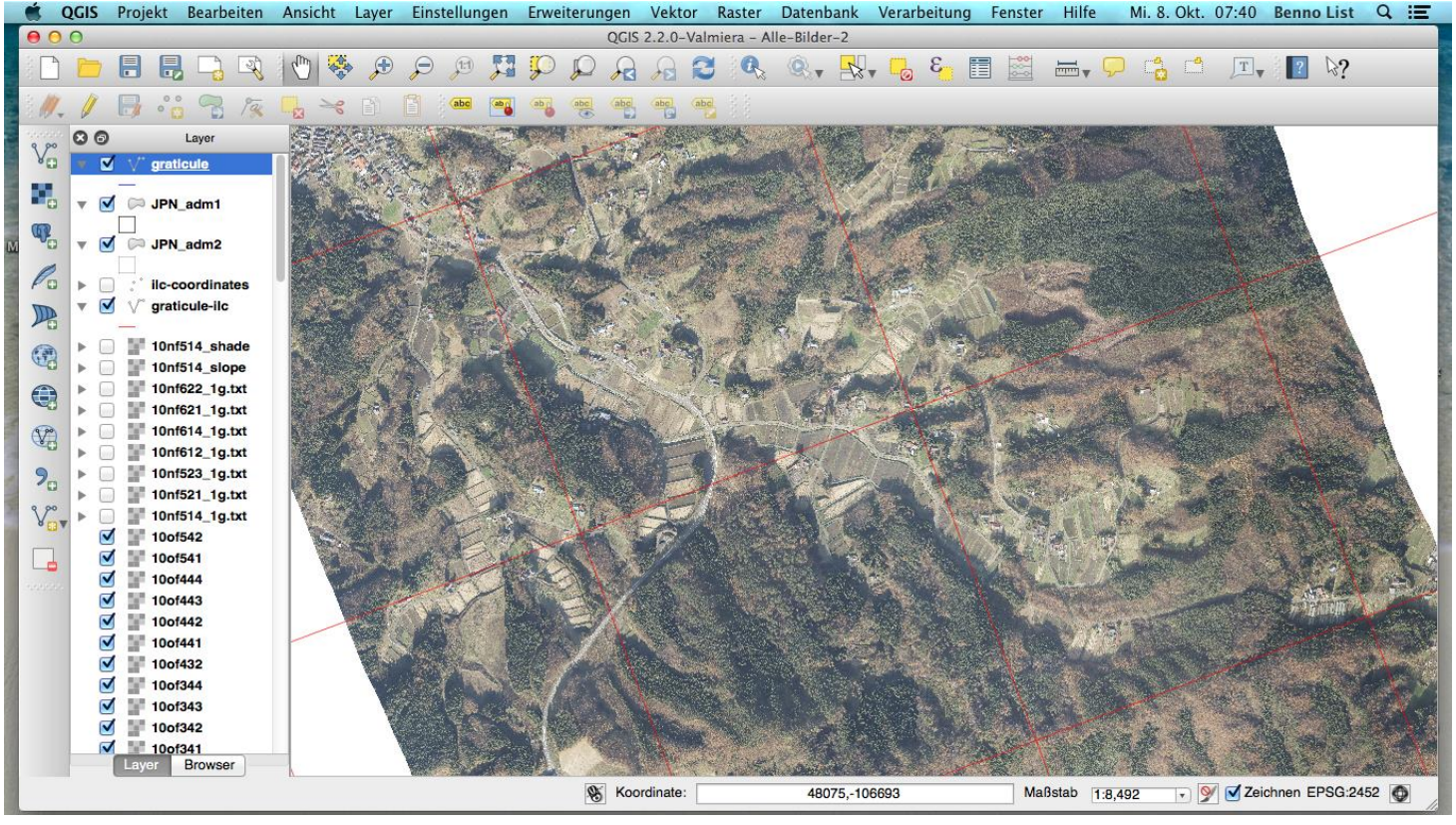
# Using a CRS in a GIS system



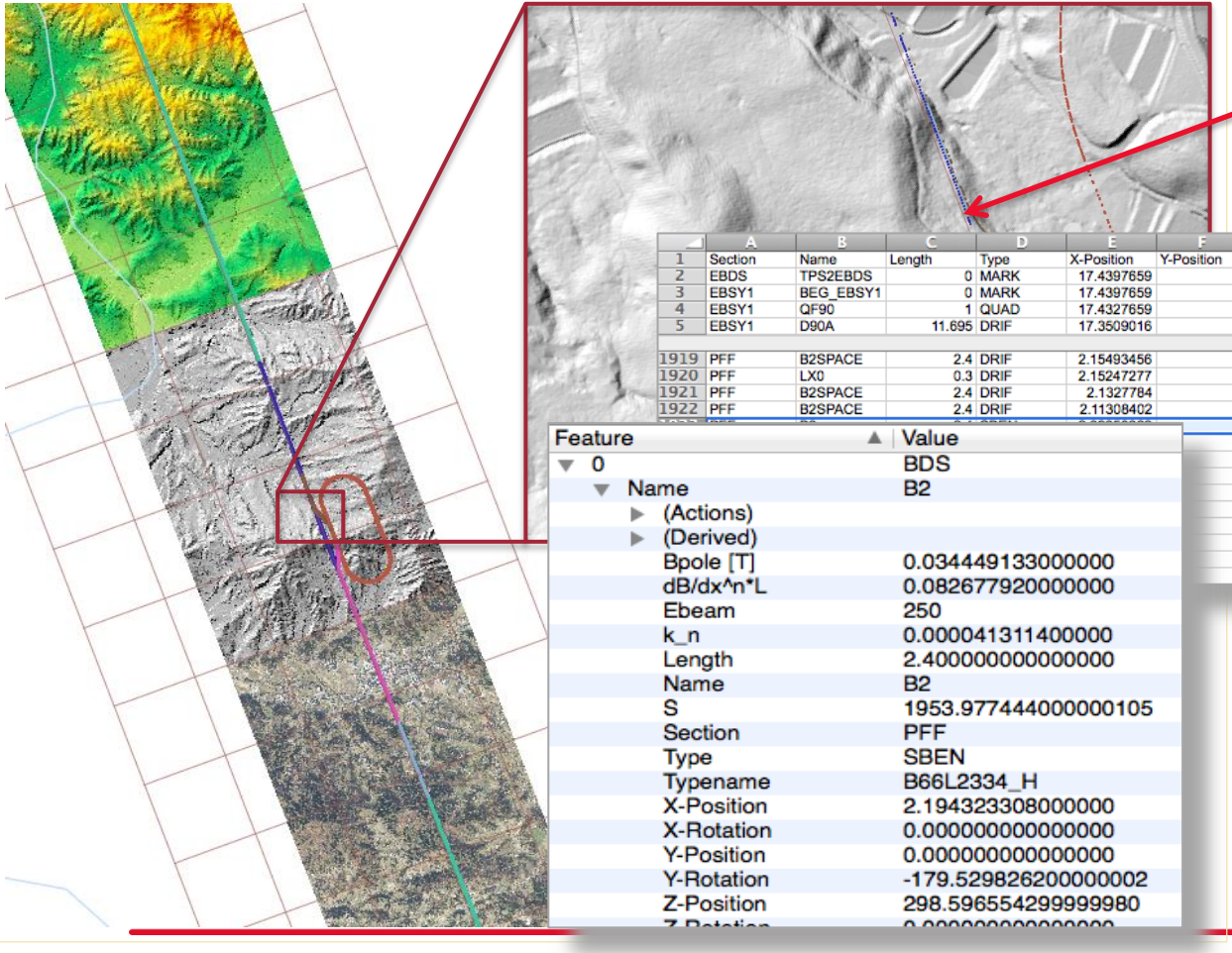
# Using a CRS in a GIS system



# Using a CRS in a GIS system



# Showing the Accelerator in a GIS System

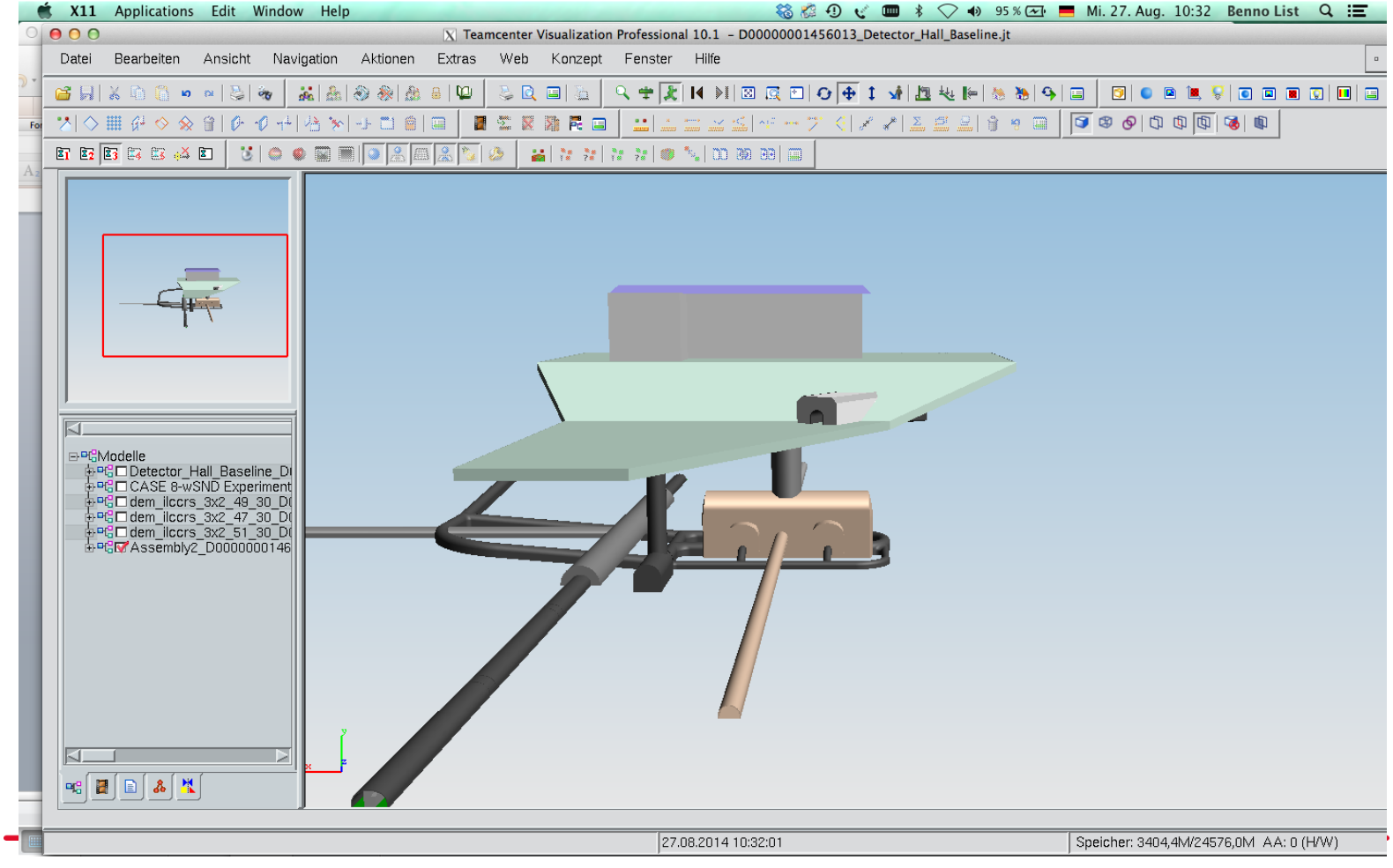


Lattice components directly imported from component lists!

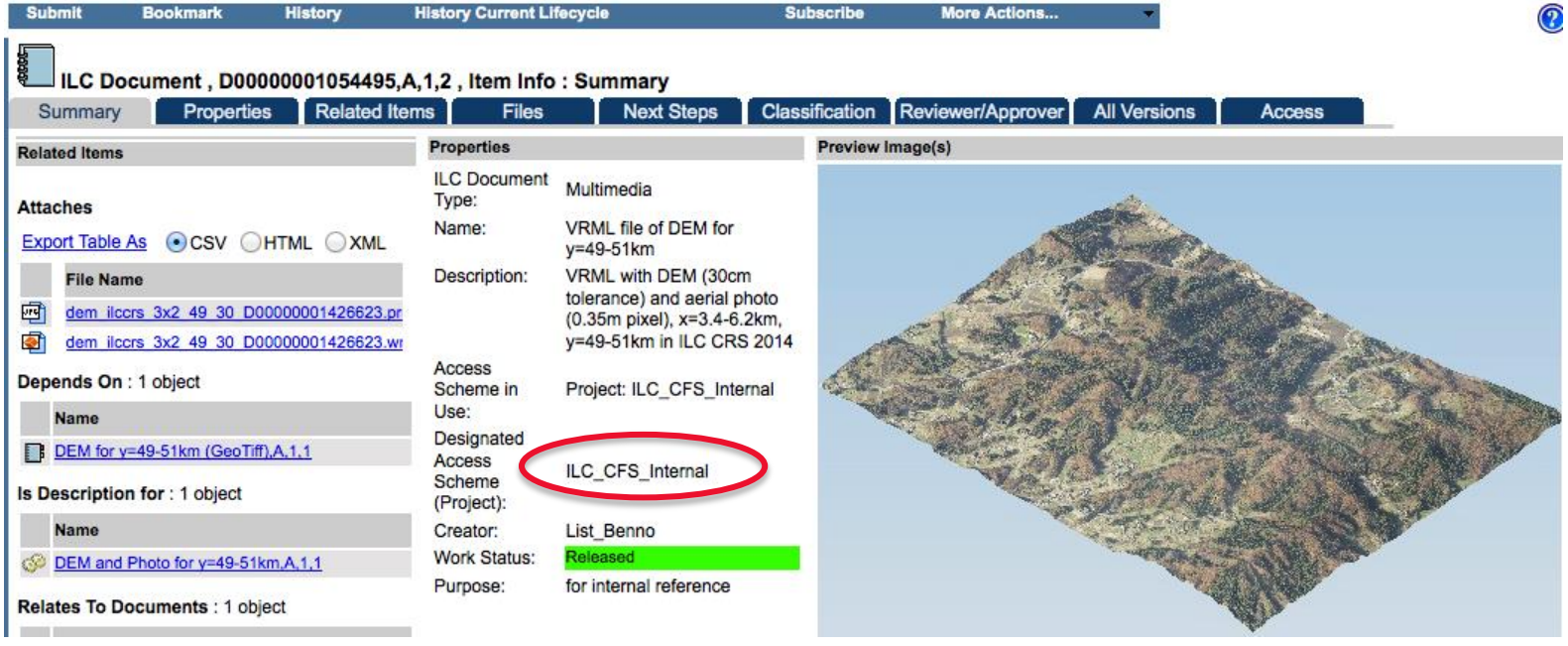
| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Section | Name | Length | Type | X-Position | Y-Position | Z-Position | X-Rotation | Y-Rotation | Z-Rotation | S | Typename |
| 2 | EBDS | TPS2EBDS | 0 | MARK | 17.4397659 | 0 | -2253.4635 | 0 | -0.4010705 | 0 | 0 | |
| 3 | EBSY1 | BEG_EBSY1 | 0 | MARK | 17.4397659 | 0 | -2253.4635 | 0 | -0.4010705 | 0 | 0 | |
| 4 | EBSY1 | QF90 | 1 | QUAD | 17.4327659 | 0 | -2252.4635 | 0 | -0.4010705 | 0 | 1 | Q16L992 |
| 5 | EBSY1 | D90A | 11.695 | DRIF | 17.3509016 | 0 | -2240.7688 | 0 | -0.4010705 | 0 | 12.695 | |
| 1919 | PFF | B2SPACE | 2.4 | DRIF | 2.15493456 | 0 | 293.796716 | 0 | -179.52983 | 0 | 1958.77744 | reserved |
| 1920 | PFF | LX0 | 0.3 | DRIF | 2.15247277 | 0 | 293.496726 | 0 | -179.52983 | 0 | 1959.07744 | |
| 1921 | PFF | B2SPACE | 2.4 | DRIF | 2.1327784 | 0 | 291.096807 | 0 | -179.52983 | 0 | 1961.47744 | reserved |
| 1922 | PFF | B2SPACE | 2.4 | DRIF | 2.11308402 | 0 | 288.696888 | 0 | -179.52983 | 0 | 1963.87744 | reserved |
| | | | | | | 0 | 286.296968 | 0 | -179.53551 | 0 | 1966.27744 | B66L2334_H |
| | | | | | | 0 | 283.897046 | 0 | -179.53551 | 0 | 1968.67744 | reserved |
| | | | | | | 0 | 281.497125 | 0 | -179.53551 | 0 | 1971.07744 | reserved |
| | | | | | | 0 | 281.197135 | 0 | -179.53551 | 0 | 1971.37744 | |
| | | | | | | 0 | 278.797214 | 0 | -179.53551 | 0 | 1973.77744 | reserved |
| | | | | | | 0 | 276.397293 | 0 | -179.53551 | 0 | 1976.17744 | reserved |
| | | | | | | 0 | 273.997371 | 0 | -179.54119 | 0 | 1978.57744 | B66L2334_H |
| | | | | | | 0 | 271.597448 | 0 | -179.54119 | 0 | 1980.97744 | reserved |
| | | | | | | 0 | 269.197525 | 0 | -179.54119 | 0 | 1983.37744 | reserved |
| | | | | | | 0 | 268.897534 | 0 | -179.54119 | 0 | 1983.67744 | |

| Feature | Value |
|---|---|
| 0 | BDS |
| Name | B2 |
| (Actions) | |
| (Derived) | |
| Bpole [T] | 0.034449133000000 |
| dB/dx^n*L | 0.082677920000000 |
| Ebeam | 250 |
| k_n | 0.000041311400000 |
| Length | 2.400000000000000 |
| Name | B2 |
| S | 1953.977444000000105 |
| Section | PFF |
| Type | SBEN |
| Typename | B66L2334_H |
| X-Position | 2.194323308000000 |
| X-Rotation | 0.000000000000000 |
| Y-Position | 0.000000000000000 |
| Y-Rotation | -179.529826200000002 |
| Z-Position | 298.596554299999980 |

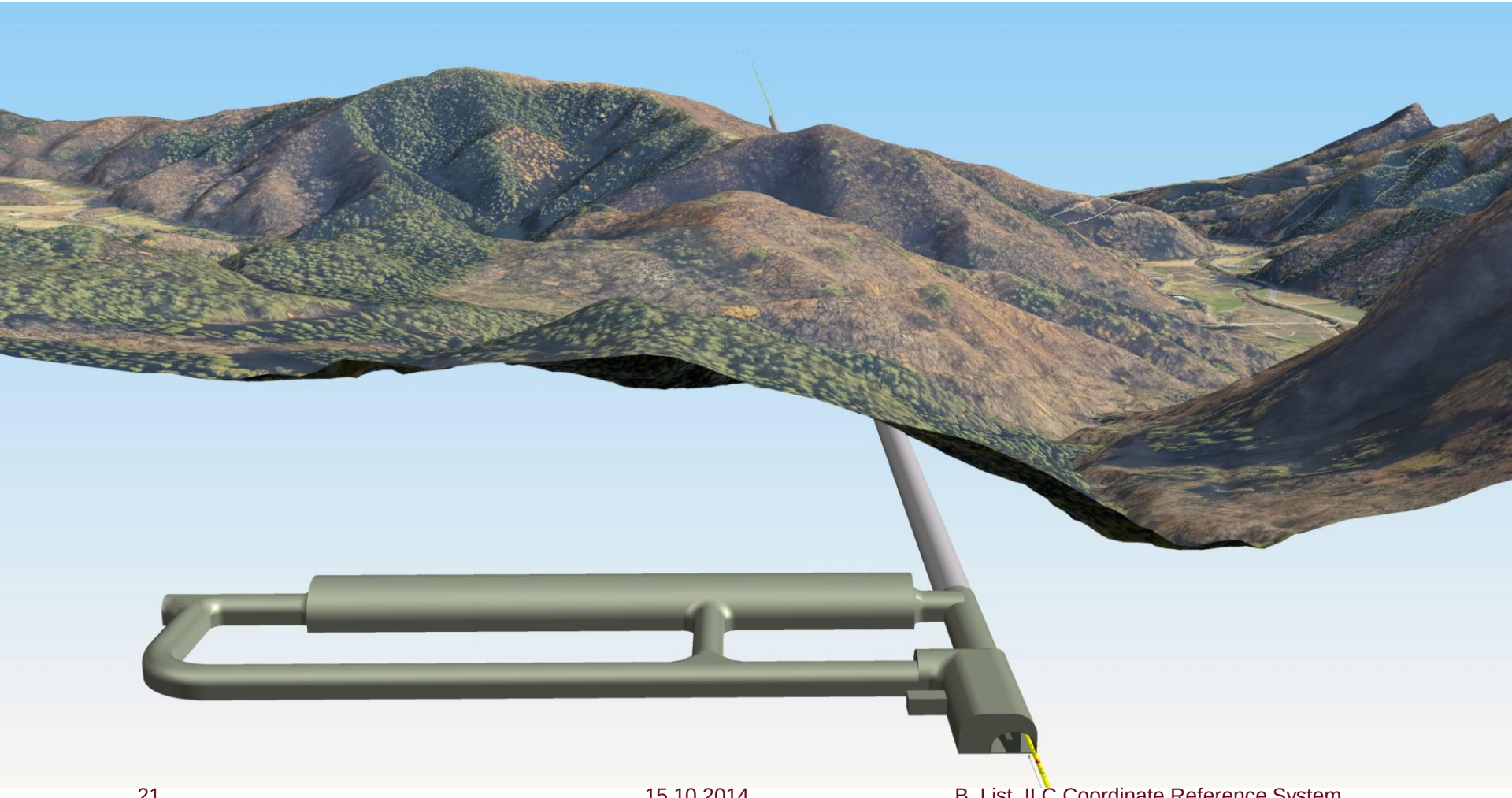
# Example for CAD



# Data based on ILC CRS in EDMS




Available: Elevation model (1m spacial resolution, 35cm height accuracy)
+ aerial view (35cm pixels)
Formats: 3D model as JT and VRML, aerial view as JPG
29 Tiles of size 2 x 2.8km, mapped to ILC CRS
Confidentiality: in ILC_CFS_Internal project



# Combining CAD Data: Reference Points

international linear collider

## ILC Reference Points for Civil Engineering

| | | | | |
|---|---|---|---|---|
| | Version | | 2.95 | 06.05.14 |

| | | KCS (America, Europe) | | | DKS (Asia) | | |
|---|---|---|---|---|---|---|---|
| Reference Point | Description | x [m] | y [m] | z [m] | x [m] | y [m] | z [m] |
| BEGEBC1 | Begin Electron Bunch Compressor 1 | 112.896 | 0.000 | -15667.757 | 113.228 | 0.000 | -15715.104 |
| TERTML2ML | Electron RTML to Main Linac | 104.525 | 0.000 | -14471.780 | 104.856 | 0.000 | -14519.127 |
| MSHAFTPMM12 | Nominal Shaft PM-12 location | 97.450 | 0.000 | -13461.123 | 95.851 | 0.000 | -13232.784 |
| MSHAFTPMM11 | Nominal Shaft PM-11 location | 83.335 | 0.000 | -11444.808 | 78.674 | 0.000 | -10778.965 |
| MSHAFTPMM10 | Nominal Shaft PM-10 location | 69.221 | 0.000 | -9428.494 | 61.497 | 0.000 | -8325.145 |
| MSHAFTPMM9 | Nominal Shaft PM-9 location | 55.106 | 0.000 | -7412.179 | 44.320 | 0.000 | -5871.325 |
| MSHAFTPMM8 | Nominal Shaft PM-8 location | 40.992 | 0.000 | -5395.864 | 27.117 | 0.000 | -3413.679 |
| MSHAFTPMM7 | Nominal Shaft PM-7 location | 34.201 | 0.000 | -4425.662 | | | |
| TEML2PS | Electron Main Linac to Positron Source (Undulator Section) | 26.540 | 0.000 | -3331.319 | 26.540 | 0.000 | -3331.319 |
| PTARGET | Positron target | 19.355 | 0.000 | -2305.000 | 19.355 | 0.000 | -2305.000 |
| TPS2EBDS | Positron Source (Undulator Section) to Electron BDS | 17.440 | 0.000 | -2253.464 | 17.440 | 0.000 | -2253.464 |
| ETUDUMP | Electron Tuneup-Dump | 8.293 | 0.000 | -1376.513 | 8.293 | 0.000 | -1376.513 |
| EMUSP1 | Electron Side Muon Spoiler 1 (res) | 5.339 | 0.000 | -647.950 | 5.339 | 0.000 | -647.950 |
| BEGPLTR | Positron source: start of transfer tunnel | 6.221 | 0.000 | -428.689 | 6.221 | 0.000 | -428.689 |
| PDUMP | Positron Main Dump | -2.104 | 0.000 | -300.575 | -2.104 | 0.000 | -300.575 |
| IP | Interaction Point | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

D00000000982315

# Combining CAD Data: List of models

international linear collider

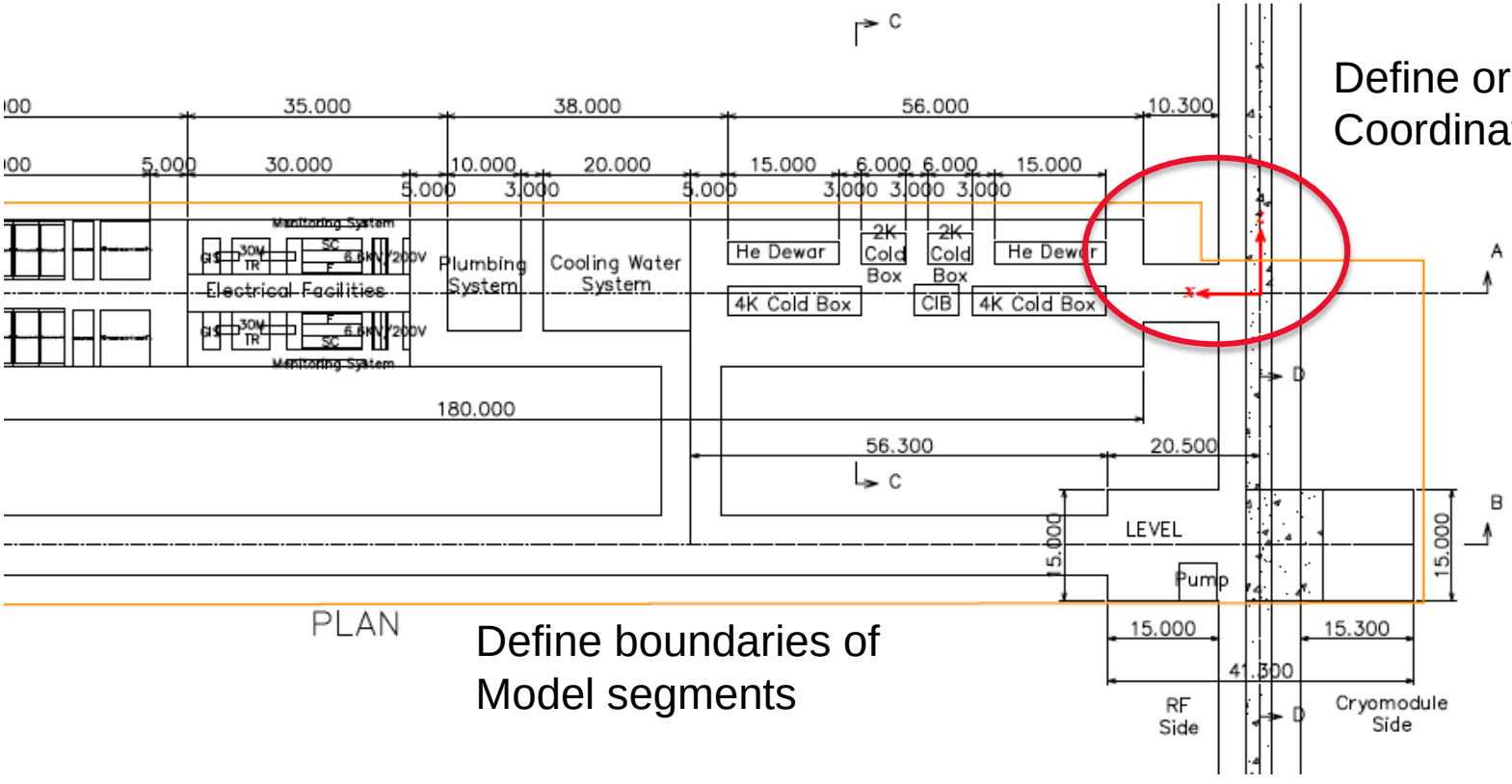
ILC Base Orphan (BO) Points

Version 2.95 06.05.14

| | | | | Reference Point Coordinates | | | local Coordinates of Reference Poi | | | BO (Base Orphan) Coordinates | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Building | Description | EDMS ID | Reference Point | x [m] | y [m] | z [m] | x [m] | y [m] | z [m] | x [m] | y [m] | z [m] | hor angle | vert ar |
| Exp_Hall_UXB0 | Experimental hall | D00000001125663 | IP | 0.000 | 0.000 | 0.000 | 0.000 | 1.100 | 0.000 | 0.000 | -1.100 | 0.000 | 0 | |
| Cry_Hall_UH-12 | Cryogenics Hall UH-12 | D00000001424913 | MSHAFTPMM12 | 95.851 | 0.000 | -13232.784 | -4.500 | 1.100 | 0.000 | 100.351 | -1.100 | -13232.784 | -0.401 | |
| Cry_Hall_UH-10 | Cryogenics Hall UH-10 | D00000001424923 | MSHAFTPMM10 | 61.497 | 0.000 | -8325.145 | -4.500 | 1.100 | 0.000 | 65.997 | -1.100 | -8325.145 | -0.401 | |
| Cry_Hall_UH-8 | Cryogenics Hall UH-8 | D00000001424933 | MSHAFTPMM8 | 27.117 | 0.000 | -3413.679 | -4.500 | 1.100 | 0.000 | 31.617 | -1.100 | -3413.679 | -0.401 | |
| Cry_Hall_UH+8 | Cryogenics Hall UH+8 | D00000001426393 | MSHAFTPMP8 | 18.010 | 0.000 | 2334.874 | -4.500 | 1.100 | 0.000 | 22.510 | -1.100 | 2334.874 | 0.401 | |
| Cry_Hall_UH+10 | Cryogenics Hall UH+10 | D00000001426413 | MSHAFTPMP10 | 51.576 | 0.000 | 7129.974 | -4.500 | 1.100 | 0.000 | 56.076 | -1.100 | 7129.974 | 0.401 | |
| Cry_Hall_UH+12 | Cryogenics Hall UH+12 | D00000001426423 | MSHAFTPMP12 | 85.930 | 0.000 | 12037.614 | -4.500 | 1.100 | 0.000 | 90.430 | -1.100 | 12037.614 | 0.401 | |
| Serv_Hall_US-13 | Services Hall US-13 | D00000001368993 | BEGEBC1 | 113.228 | 0.000 | -15715.104 | -4.500 | 1.100 | 0.000 | 117.728 | -1.100 | -15715.104 | -0.401 | |
| Serv_Hall_US+13 | Services Hall US+13 | D00000001368993 | BEGPBC1 | 101.574 | 0.000 | 14272.425 | -4.500 | 1.100 | 0.000 | 106.074 | -1.100 | 14272.425 | -0.401 | |
| Turn_R-13 | Turnaround Tunnel R-13 | D0000000xxxxxx3 | BEGEBC1 | 113.228 | 0.000 | -15715.104 | -4.500 | 1.100 | 0.000 | 117.728 | -1.100 | -15715.104 | 0.401 | |
| Tunnel_T-12 | Tunnel T-12 (RTML, Bunch Compressor, e- ML) | D0000000xxxxxx3 | MSHAFTPMM12 | 95.851 | 0.000 | -13232.784 | -4.500 | 1.100 | 2502.217 | 100.351 | -1.100 | -15735.001 | -0.401 | |
| Tunnel_T-11 | Tunnel T-11 (e- ML) | D00000001425733 | MSHAFTPMM12 | 95.851 | 0.000 | -13232.784 | -4.500 | 1.100 | -10.300 | 100.351 | -1.100 | -13222.484 | -0.401 | |
| Tunnel_T-10 | Tunnel T-10 (e- ML) | D00000001425743 | MSHAFTPMM11 | 78.674 | 0.000 | -10778.965 | -4.500 | 1.100 | 0.000 | 83.174 | -1.100 | -10778.965 | -0.401 | |
| Tunnel_T-9 | Tunnel T-9 (e- ML) | D00000001425713 | MSHAFTPMM10 | 61.497 | 0.000 | -8325.145 | -4.500 | 1.100 | -10.300 | 65.997 | -1.100 | -8314.845 | -0.401 | |
| Tunnel_T-8 | Tunnel T-8 (e- ML) | D00000001425723 | MSHAFTPMM9 | 44.320 | 0.000 | -5871.325 | -4.500 | 1.100 | 0.000 | 48.820 | -1.100 | -5871.325 | -0.401 | |
| Tunnel_T-7 | Tunnel T-7 (Undulator) | D0000000xxxxxx3 | MSHAFTPMM8 | 27.117 | 0.000 | -3413.679 | -3.000 | 1.100 | 0.000 | 30.117 | -1.100 | -3413.679 | -0.401 | |
| Tunnel_T-6 | Tunnel T-6 (Electron dogleg) | D0000000xxxxxx3 | MSHAFTPMM8 | 27.117 | 0.000 | -3413.679 | -3.000 | 1.100 | 0.000 | 30.117 | -1.100 | -3413.679 | -0.401 | |
| | | | | | | | | | | | | | | |
| Tunnel_T+8 | Tunnel T+8 (e+ ML) | D00000001426443 | MSHAFTPMP8 | 18.010 | 0.000 | 2334.874 | -4.500 | 1.100 | -92.8 | 22.510 | -1.100 | 2427.674 | 0.401 | |
| Tunnel_T+9 | Tunnel T+9 (e+ ML) | D00000001426433 | MSHAFTPMP9 | 34.399 | 0.000 | 4676.155 | -4.500 | 1.100 | 0 | 38.899 | -1.100 | 4676.155 | 0.401 | |
| Tunnel_T+10 | Tunnel T+10 (e+ ML) | D00000001426463 | MSHAFTPMP10 | 51.576 | 0.000 | 7129.974 | -4.500 | 1.100 | -92.8 | 56.076 | -1.100 | 7222.774 | 0.401 | |
| Tunnel_T+11 | Tunnel T+11 (e+ ML) | D00000001426453 | MSHAFTPMP11 | 68.753 | 0.000 | 9583.794 | -4.500 | 1.100 | 0 | 73.253 | -1.100 | 9583.794 | 0.401 | |

- Complete CAD model (buildings, lattices, detectors, surface) is assembled from JT files in a visview session (not in CAD system)
- -> result in EDMS: D00000001420943
- Method well established for XFEL project,
- independent from CAD native file format
- Requires agreed segmentation of 3D models, with local coordinate systems

# Segmentation: Example for Cryo Hall




Define origin of local Coordinate System

Define boundaries of Model segments

# Summary

- **Definition of an ILC CRS brings together geospacial data and CAD models, for use in GIS and CAD systems**
- **Enables modeling of the entire facility**
- **Applications:**
  - Interface verification
  - Interactive reviews (also in Virtual Reality rooms)
  - Vision sharing
  - Public relations
- **Design integration requires common CAD model conventions for coordinate systems, segmentation**
- **Experience from XFEL: Establish standards and conventions early, before the real work starts: Now**