Innovation in Metrology from the JAI

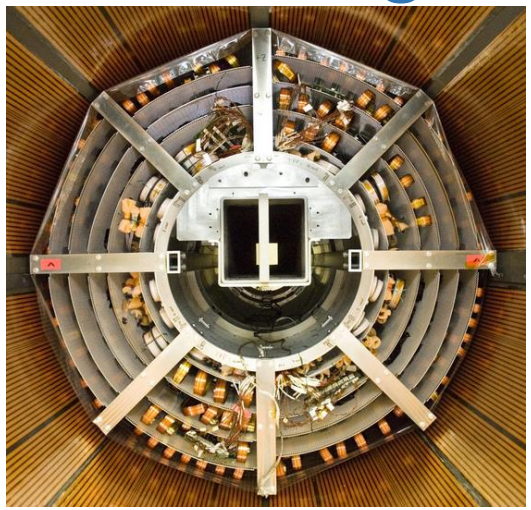
JAI Advisory Board Meeting, April 7th 2022

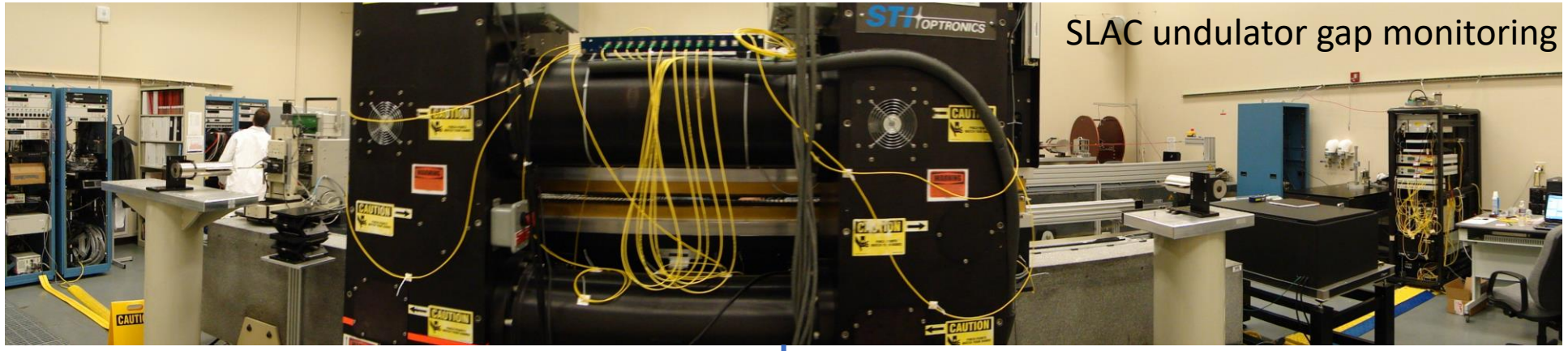
Armin Reichold

Overview

- Historic Origin's
- Technology Transfer Model
  - Goals
  - Method
  - Past performance
- Our Technology
  - Current commercial technology = Multiline
  - Current R&D technology = PaMIr
- Summary

Historic origins





Linear Collider Alignment and Survey seed corn for ground motion, stabilisation and alignments at ILC ➔ FSI technology Mark-II

STFC withdraws from ILC
WP6 terminates prematurely

1993 ATLAS SCT alignment system
Oxford FSI technology Mark-I

2003

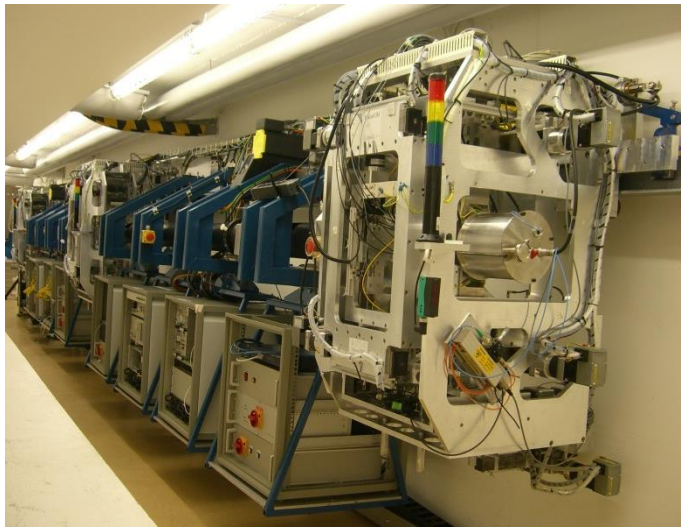
2004

2008

2009

2010

2013



Robotic Tunnel Reference Surveyor (ILC @ DESY)

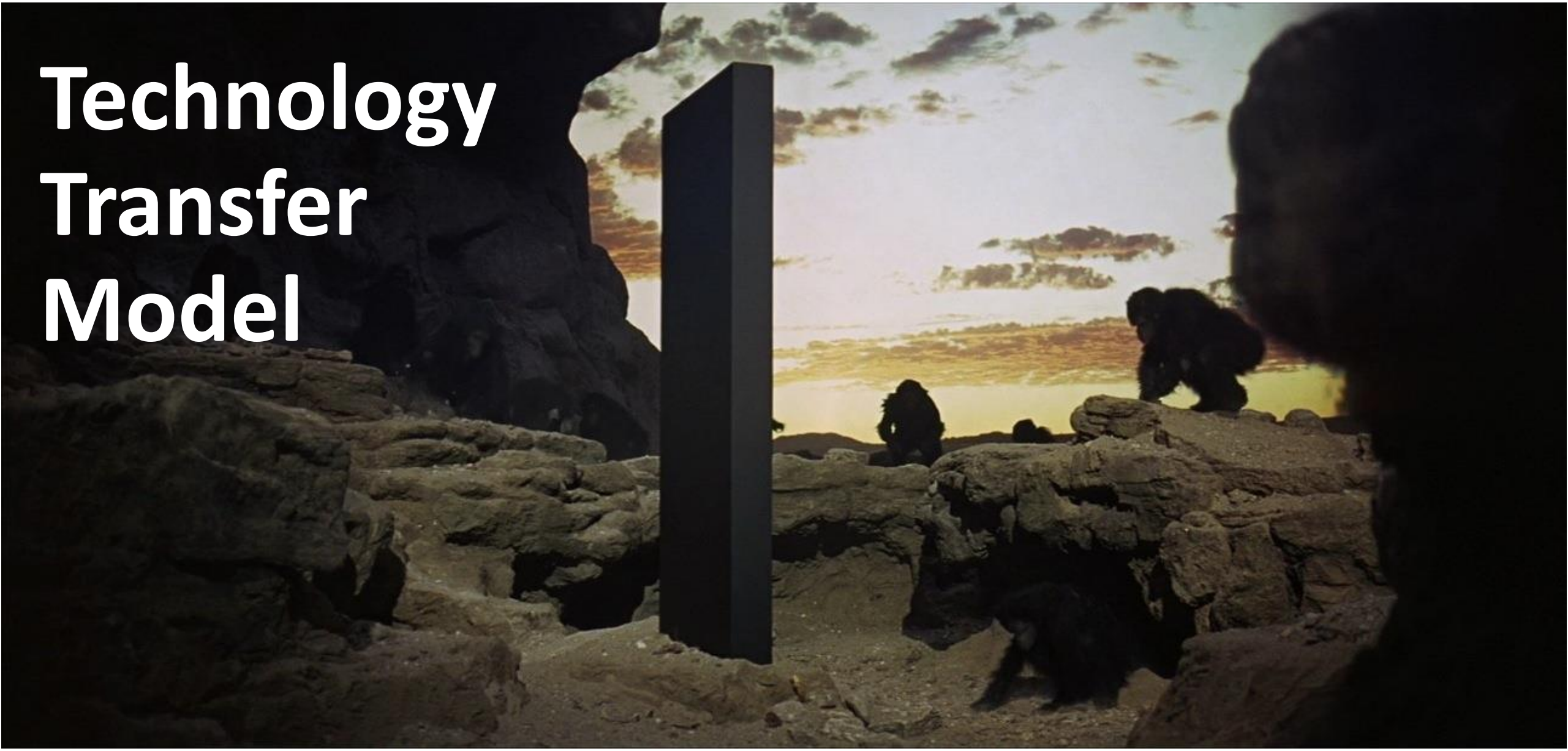
LC-ABD WP6

Reichold meets Schwenke CEO Etalon

EPSRC-NPL-ETALON-JAI
AMULET = general purpose absolute distance measurement system for laser tracers

eTALON Laser Tracer

Technology Transfer Model



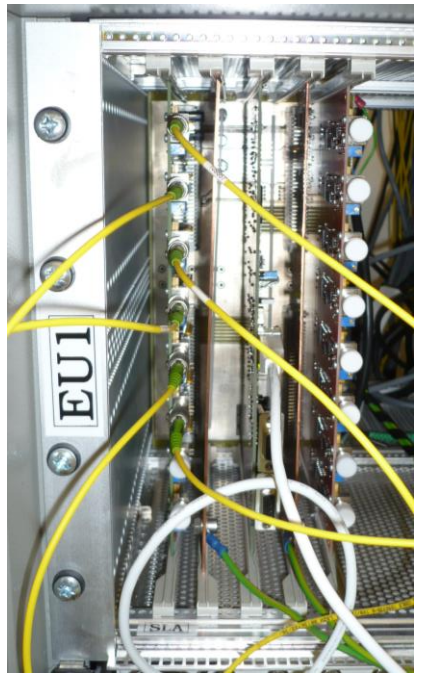
Technology Transfer Model

- Goals:
  - Generate & publish advances in science **AND** innovation
  - Increase impact of JAI technology beyond the few science projects small JAI groups can support
  - Generate revenue for University and Inventors
  - Create jobs outside of academia

Technology Transfer Model

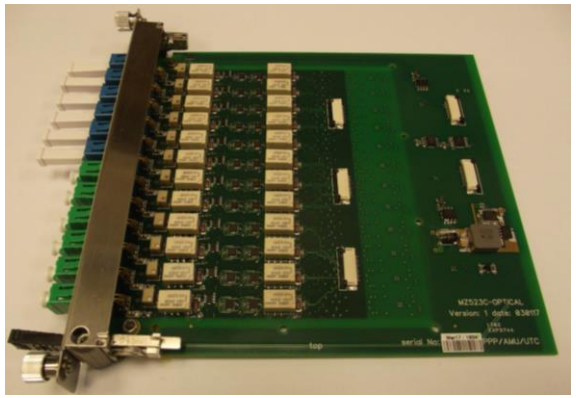
- Method:
  - Maximise utility of JAI technology through turn-key instruments, produced under license by industrial partners.
  - Development targets widest applicability
  - Protect IP with Patents (paid by Industry) then publish
  - Continuously update technology to suit science **AND** industry
    ➔ new partner for uTCA-DAQ = VadaTech
  - Long term relations with industry partners

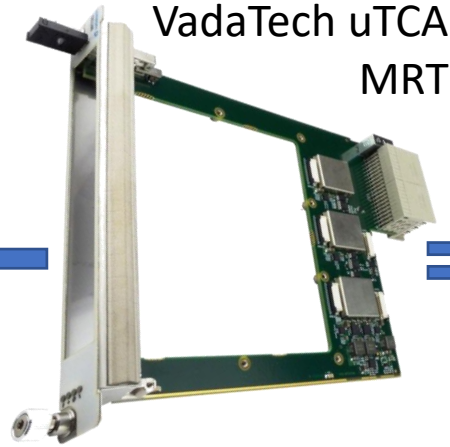
1st commercial dFSI:
DAQ fully home built
- 5U-crate
- 2.77 MHz ADC
- 8-ch opto-board



accelerator control wants uTCA & high density

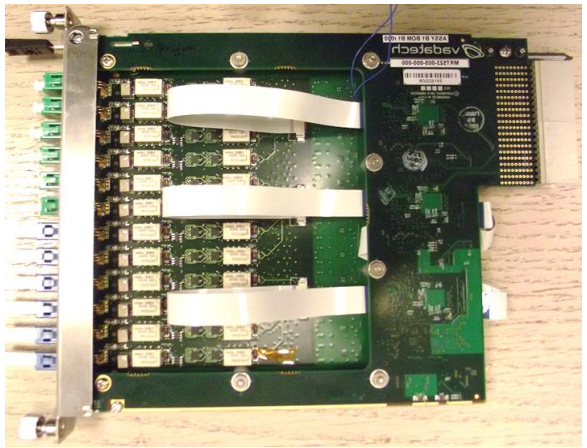
JAI optical dFSI mezzanine





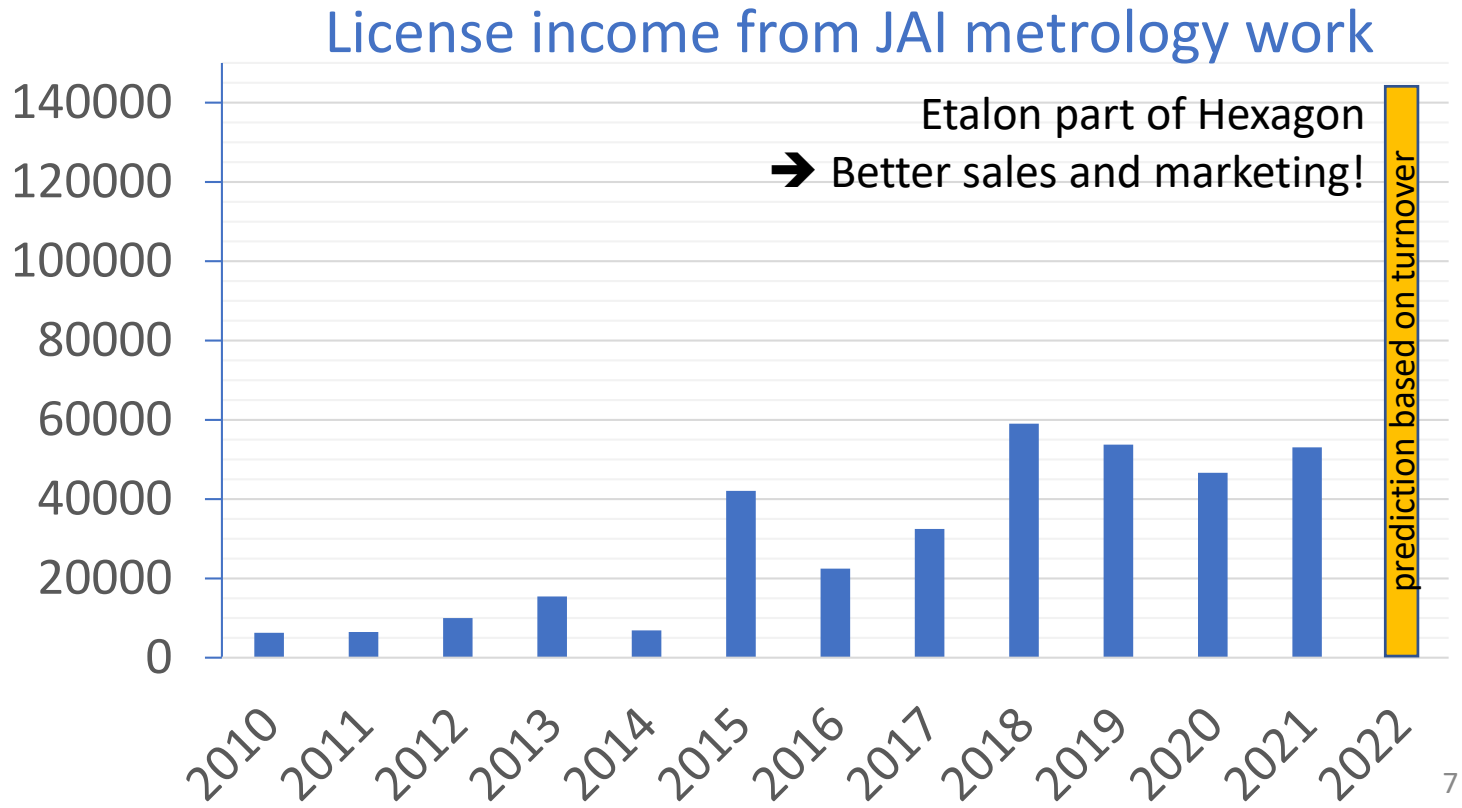
VadaTech uTCA MRT

2nd generation dFSI DAQ
full uTCA RTM, now in Gen-4



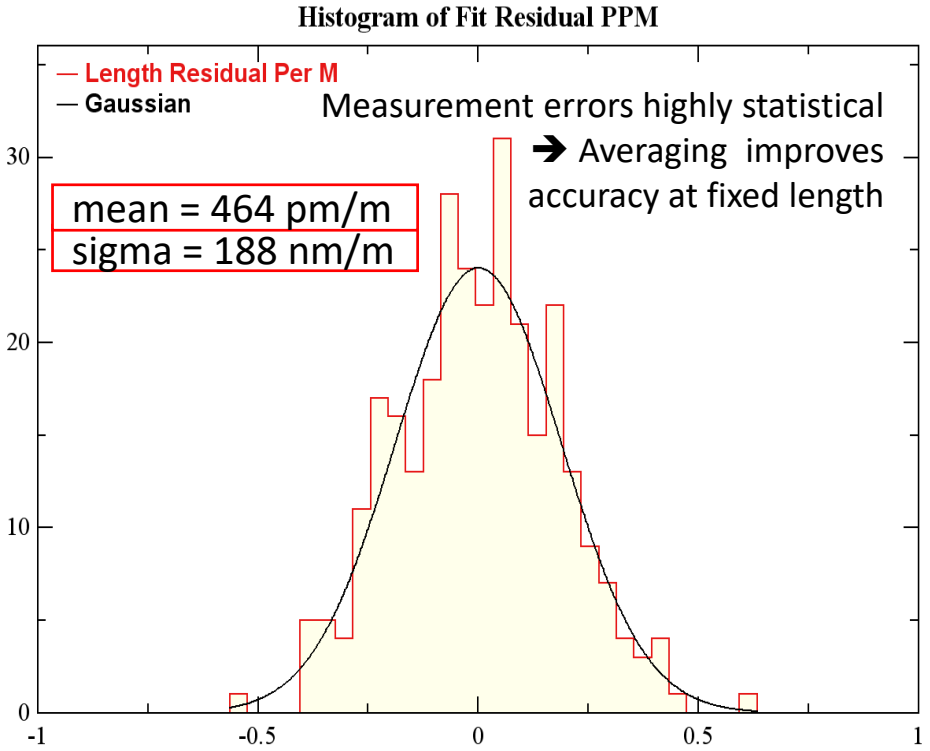
Technology Transfer Model

- Past Performance
  - Grants:
    - 3 grants for accelerator science using metrology **all before March 2010**: £2M
    - 12 grants for innovation from the above science **all after January 2010**: £1.66M
    - Industry contribution to the above **all after Jan 2010**: £0.545M
    - Only five **DPhil students 2004 to 2015** (none after that), but multiple master's & summer students
  - Industry total R&D input (productisation) : €1.5M
  - License Income
    - total since 2010 = £354,622
  - Total turnover to date: €6M
  - Expected turnover 2022: €1.8M
  - Consulting
    - 5 consulting contracts for JAI team
  - Publications from innovation only
    - 2 patents
    - 2 papers



Current Technology = Frequency Scanning Interferometry

- Measure absolute distances 15 mm – 30 m
- Dynamic measurement < 19 mm/s
- Scan time resolution 125 MHz
- Scan position resolution < ± 0.1 µm
- Scan repetition rate 0.1 to 10 Hz
- Uncertainty: < ±0.5 µm/m @ 95% confidence



statistics of ~200 measurement residuals from 0.2 to 20 m comparing against reference instrument at NPL

Current Technology Customers

- **Industry Customers:**
  - Siemens Energy (€1Bn off shore wind-energy platform monitoring),
  - SAFRAN Reosc (form metrology of 900 EELT mirrors at 20nm uncertainty),
  - DMG Pfronten (CNC machine deformation monitoring)
  - Heidenhain (calibration methods and thermal CNC monitoring)
  - Alstom: Monitoring of large machine tools
  - **Expected**: SAFRAN Reosc, 2nd system, in process telescope mirror manufacturing
- **Other Research customers:**
  - PTB (**P**hysikalisch **T**echnische **B**undesanstalt) = Campus wide FSI network ➔ test mobile metrology instruments , large ultra-precision CMM; wind energy deformation, torque-tests
  - NARMC (UK's **N**uclear **A**dvanced **M**aterials **R**esearch **C**entre, facility wide CNC and CMM machine calibration network),
  - RWTH Aachen Machine Tool Lab (deformations of CNC machines),
  - University of Dresden (deformation of robots, presses, tools),
  - **Expected**:
    Uni Hannover, positioning mobile machine tools
    Frauenhofer-IFAM, Robot Monitoring
    NASA, space component deformations in simulators
- **Accelerator customers:**
  - 2 x CERN (in-vacuum alignment of high luminosity LHC crab cavities and quadrupoles),
  - 2 x SLAC (alignment of undulator magnets at LCLS-II),
  - GSI (general purpose instrument),

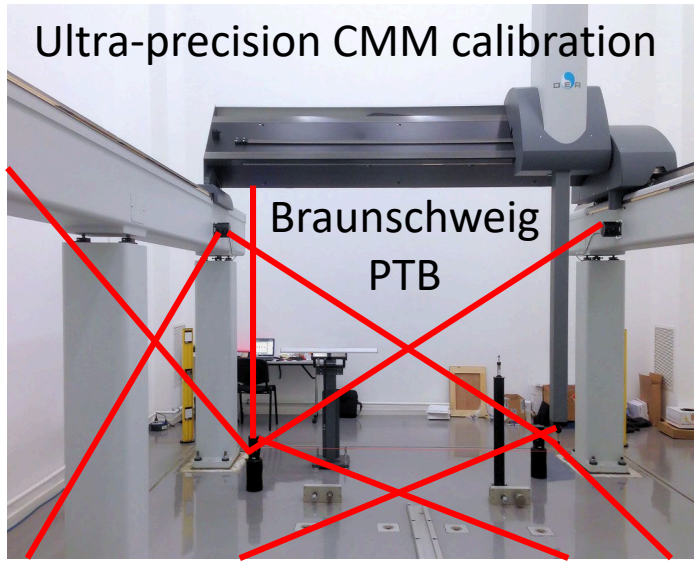
  PSI (Paul Scherrer Institute, in vacuum form measurement & alignment of X-ray mirrors for MAX IV synchrotron)
  - **Expected:** Argonne 2nd system, in vacuum XFEL alignment
- **Astronomy customers:**
  - GMT (Giant Magellan Telescope, align primary to secondary mirror, currently installed at the Large Binocular Telescope to increase usable observation time by 30 minutes per night.)
  - LBT (Large Binocular Telescope) align primary to secondary, increases usable observation time by 30 minutes per night.
  - ESO (mirror deformation measurement and alignment of Harmoni instrument in cryostat)
  - LMT (Large Millimetre Telescope), Mexico: Monitoring of secondary mirror
  - SRT (Sardinian Radio Telescope) Monitor secondary mirror
  - Russian Academy of Science (cryogenic, in-vacuum deformation tests for Millimetron Space Telescope)
  - CCAT (Cerro Chajnantor Atacama Telescope, measure form of 6m x 6m primary in situ, align prim. to secondary)
  - **Expected**: GMT 2nd system, full alignment network for GMT

Current Technology Customers

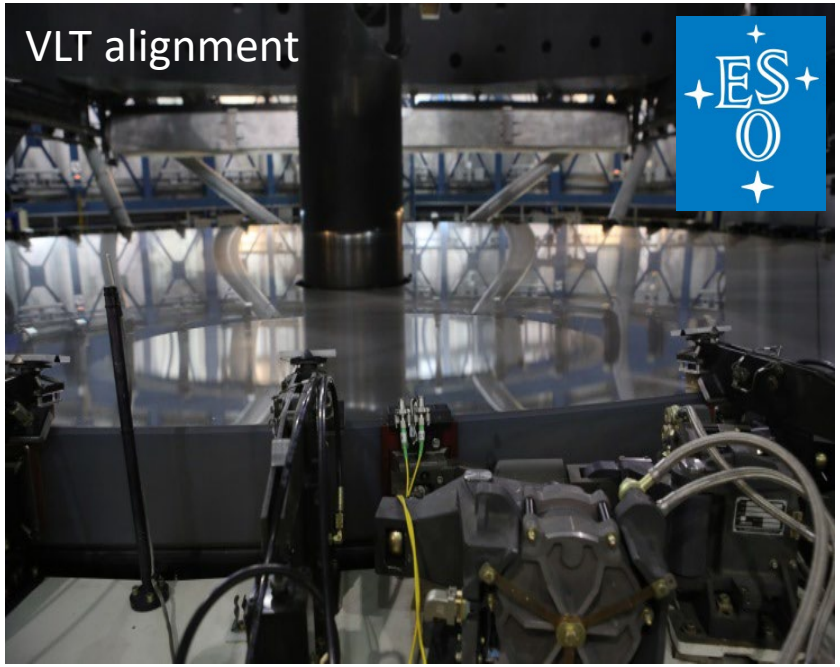
Siemens Energy (Borwin-3: €1Bn off shore wind-energy HV-DC platform monitoring, Borwin-5 interested),

Current Technology Customers

- PTB (**P**hysikalisch **T**echnische **B**undesanstalt) = Campus wide FSI fibre network ➔ test mobile metrology instruments , large ultra-precision CMM; wind energy deformation, torque-tests

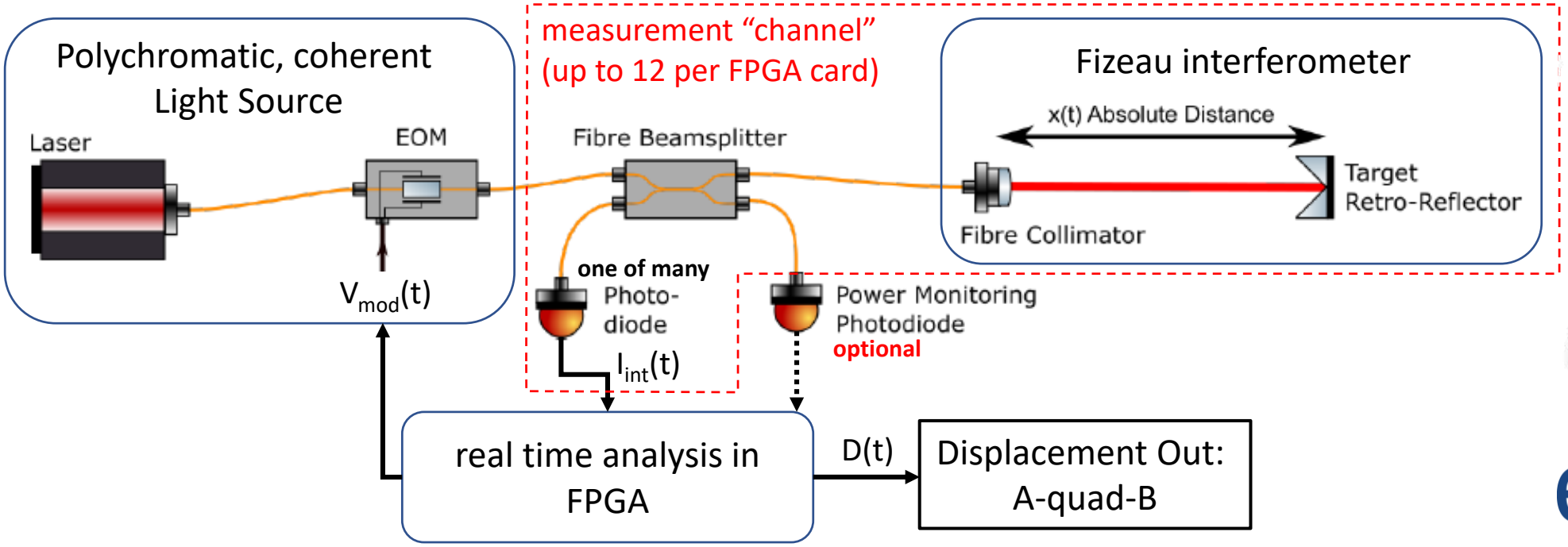


Current Technology Customers



LBT (Large Binocular Telescope) align primary to secondary, increases usable observation time by 30 minutes per night.

Next technology = PaMIr (Phase Modulation Interferometry)



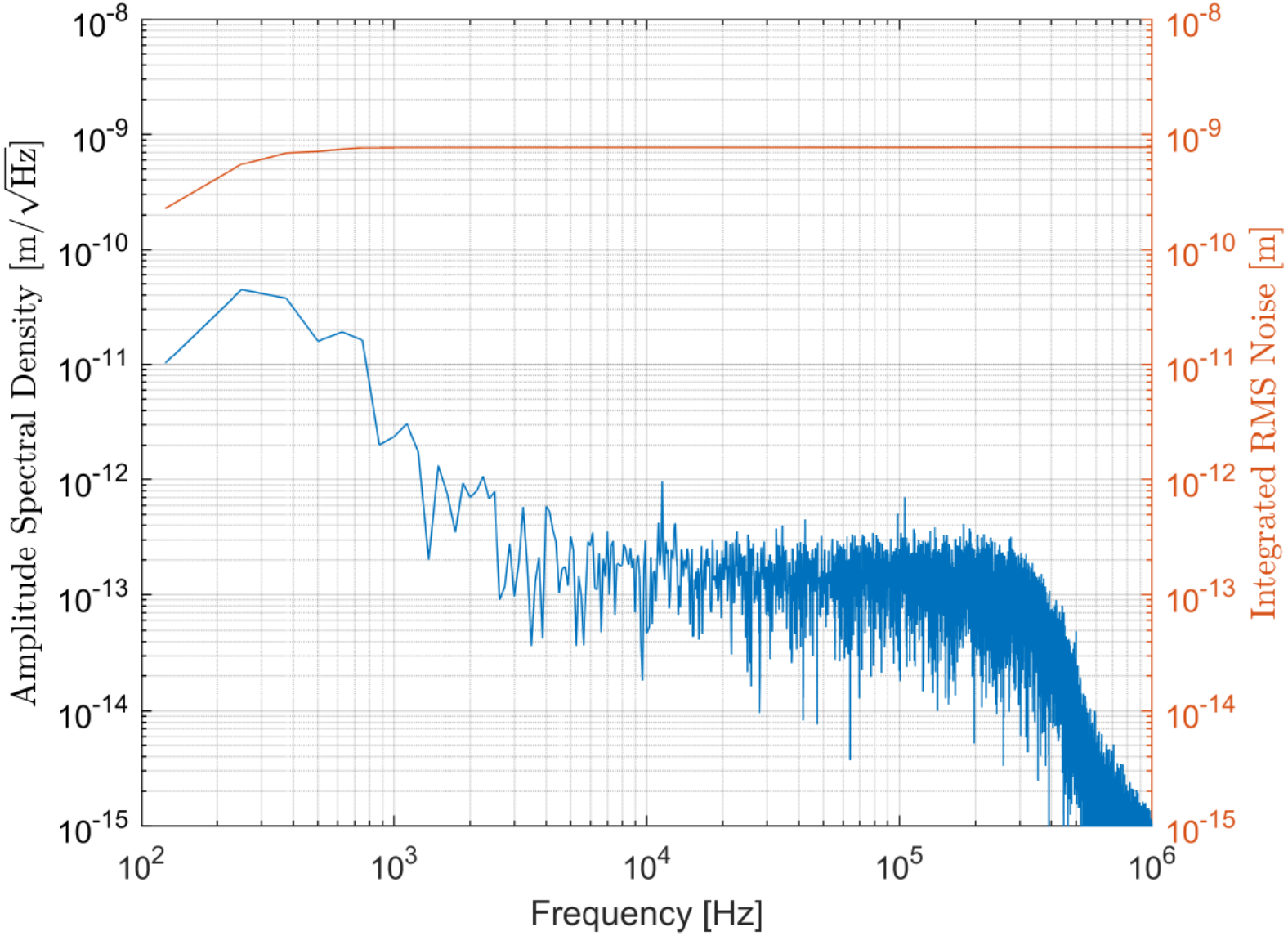
eTALON Laser Tracer
APPLIED TRACEABILITY

- Single detector, fibre coupled, multi-channel displacement sensor
- Plug compatible with Multiline™ interferometer optics and readout
- Single laser source + EDFA for up to 90 channels
- Aimed at CNC machines, real time stabilisation and laser tracers

- Maximum speed 1 m/s
- Distance range 0.1m to 30m
- Real time signal analysis in FPGA:
  - $\Delta T_{latency} <$ 10 µs (design)
  - Update rate 12.5 MHz
  - 12 channels per AMC523 (4 chan. version Sept. 2022)
- Any interferometer measures any distance inside range

Real Data results
(Displacement noise)

- RMS noise 0.8 nm up to 500 kHz (offline analys.)
- Stationary target with OPD approx. 1m
- Now verified at 1 m/s
- Realtime test expected May 2022
- Next Goal = simultaneous combination with FSI



(d) PaMIr extracted displacement noise characteristics. The RMS noise is found by integration from 0 Hz up to the desired cutoff frequency. It approaches 0.8 nm for the full bandwidth of 500 kHz

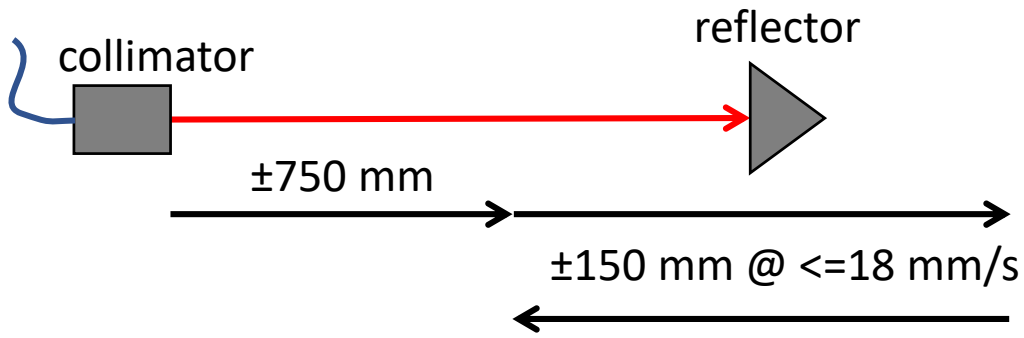
Summary

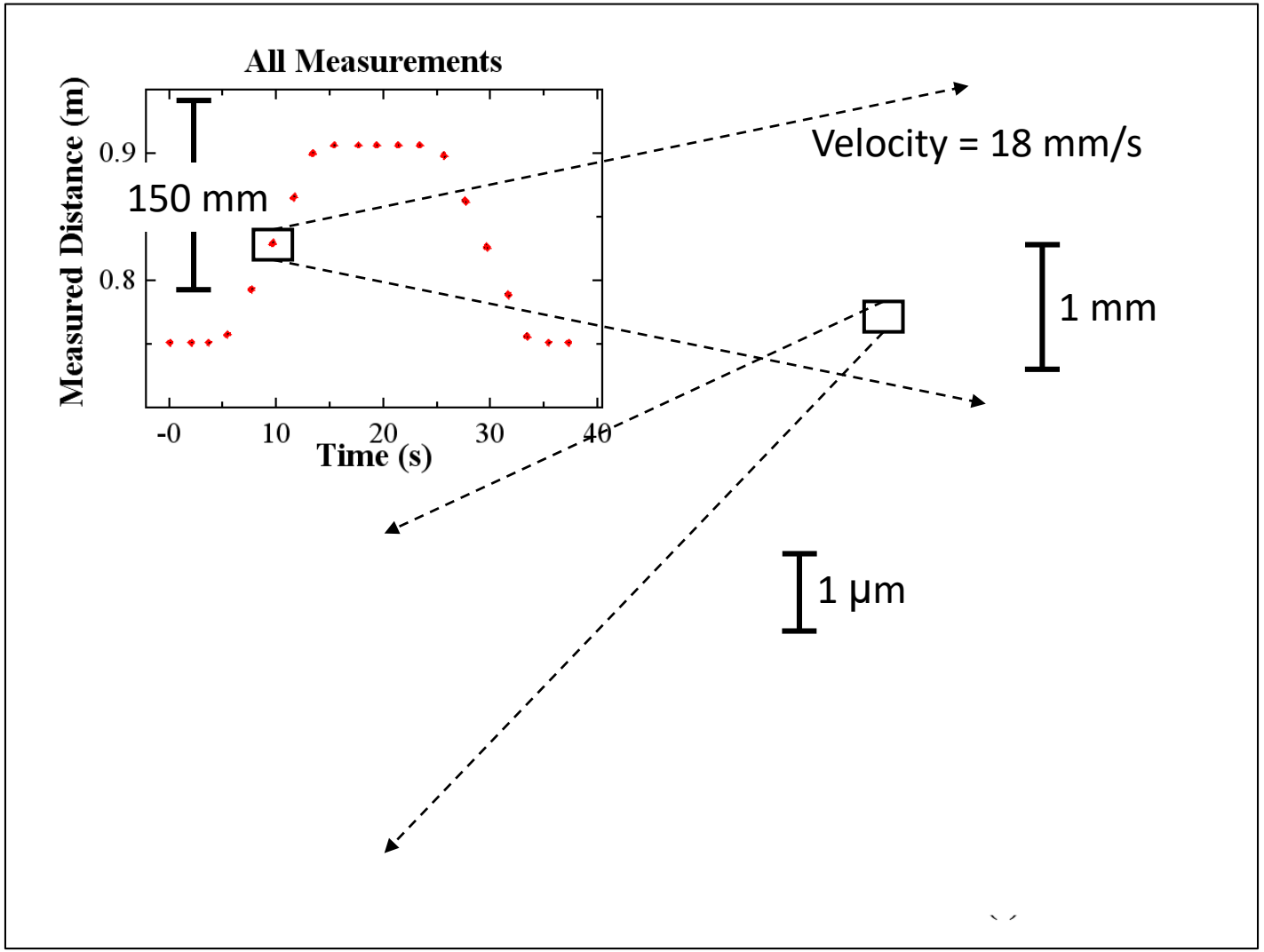
- JAI metrology work has spread far in industry, accelerator science, astronomy and other research fields
- This is a long term activity with continuous project updates.
- Funding after 2010 is hard work (small grants) and only available under the Impact Agenda but we delivered multiple projects
- Science project funding seized in 2010 ➔ How can we recover this?
- No DPhil students after 2015
- Steady income stream via licenses with growing trajectory

Backup Slides

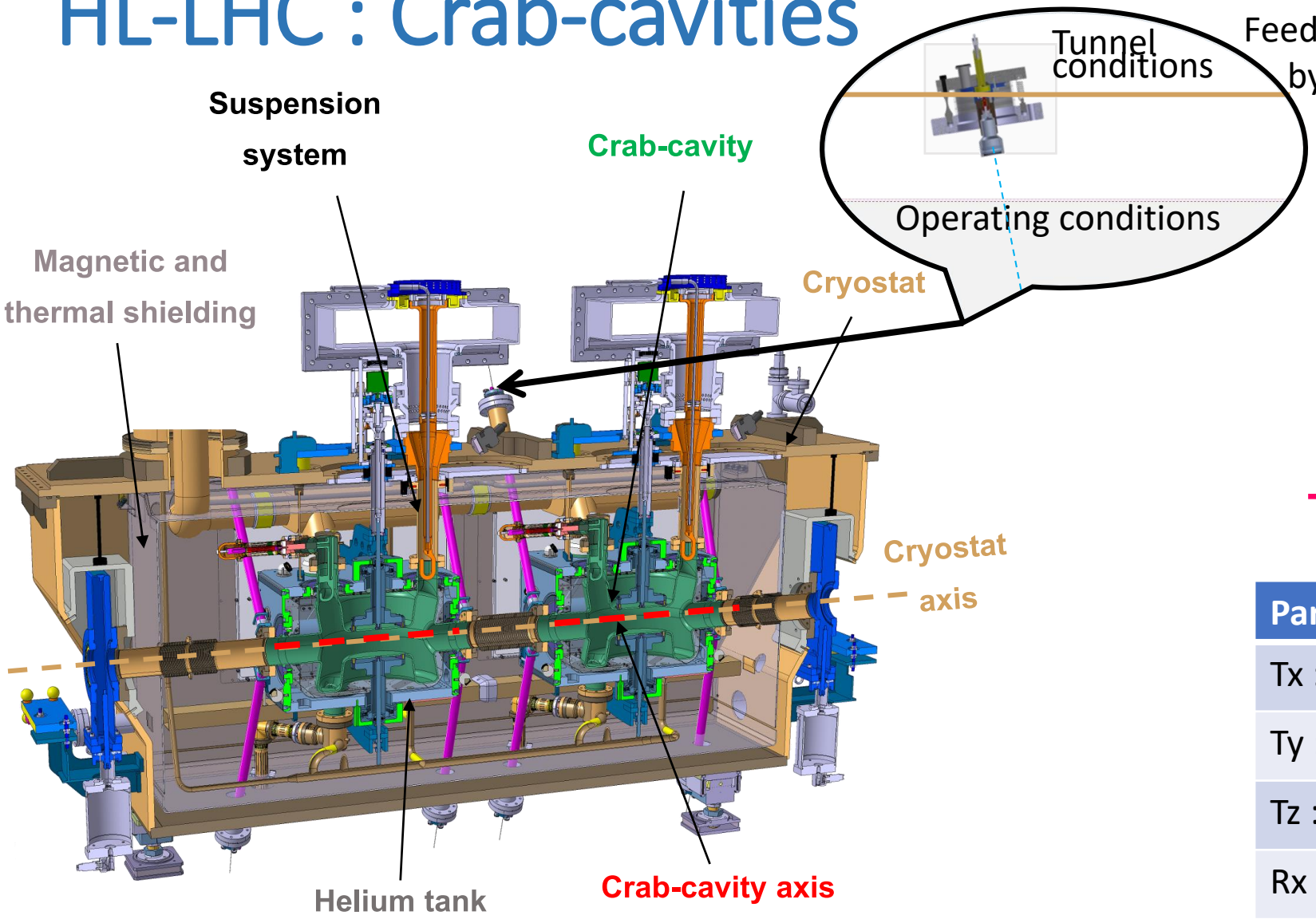
Current Technology = Frequency Scanning Interferometry

- Reflector on stepper motor stage
- L_{min} = 75 cm
- L_{max} = 90 cm
- v_{max} = 18 mm/s





HL-LHC : Crab-cavities



Feedthrough commercially developed by CERN knowledge transfer team.

Operating conditions :

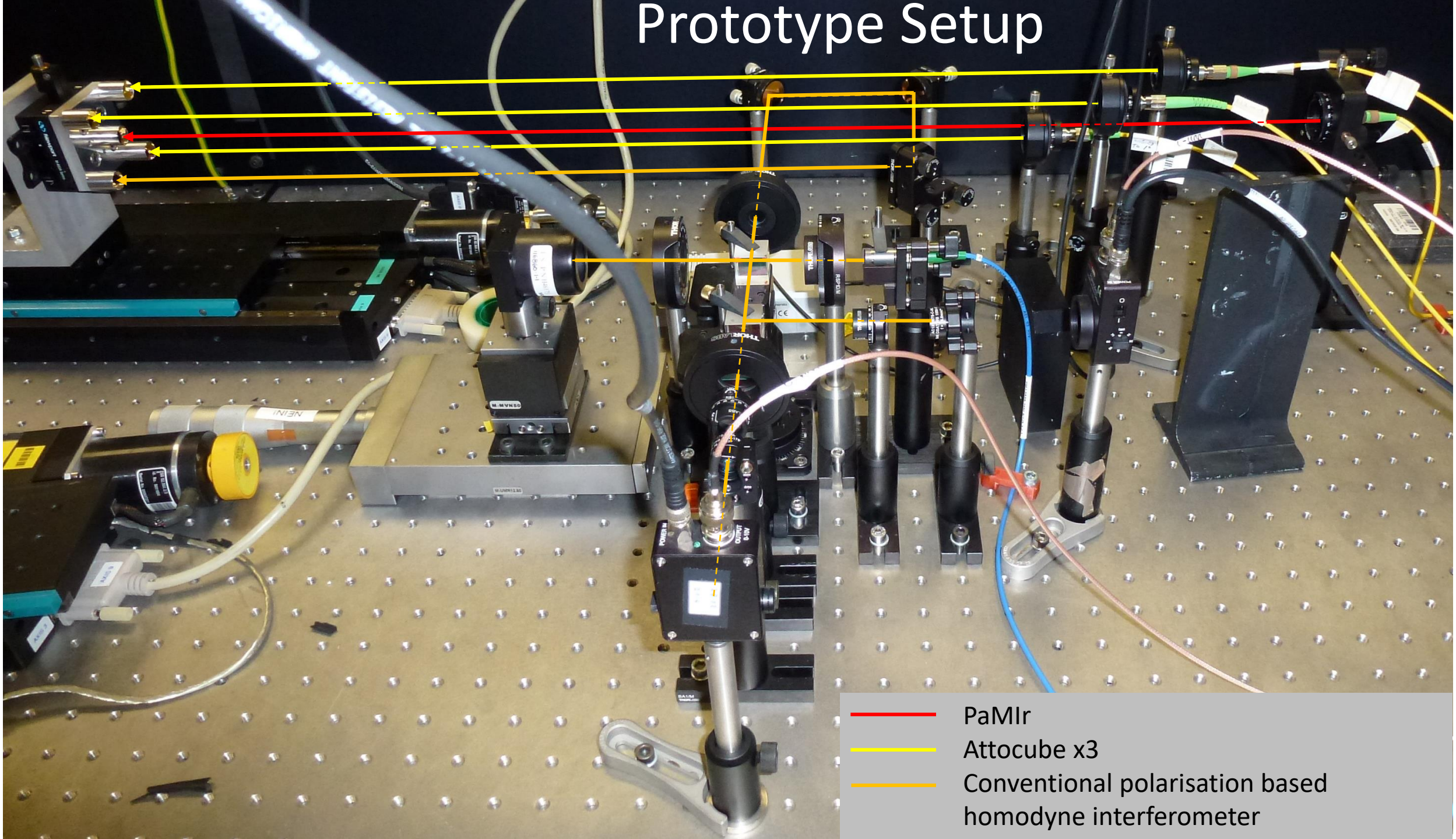
- Radiation : 1 MGy / year
- Vacuum : 10^{-6} mbar
- Temperature : 4 K

Cryostat and cavities axes → Alignment requirements : +/-0.25 mm at 3σ

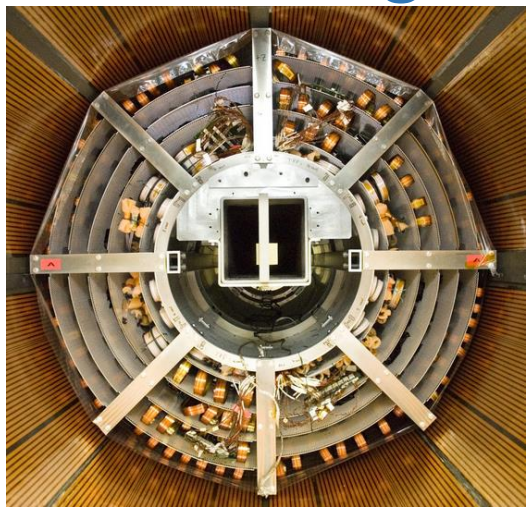
Parameters	Precision
Tx : radial (mm)	0.021
Ty : vertical (mm)	0.009
Tz : longitudinal (mm)	0.028
Rx : pitch (mrad)	0.030
Ry : yaw (mrad)	0.072
Rz : roll (mrad)	0.187

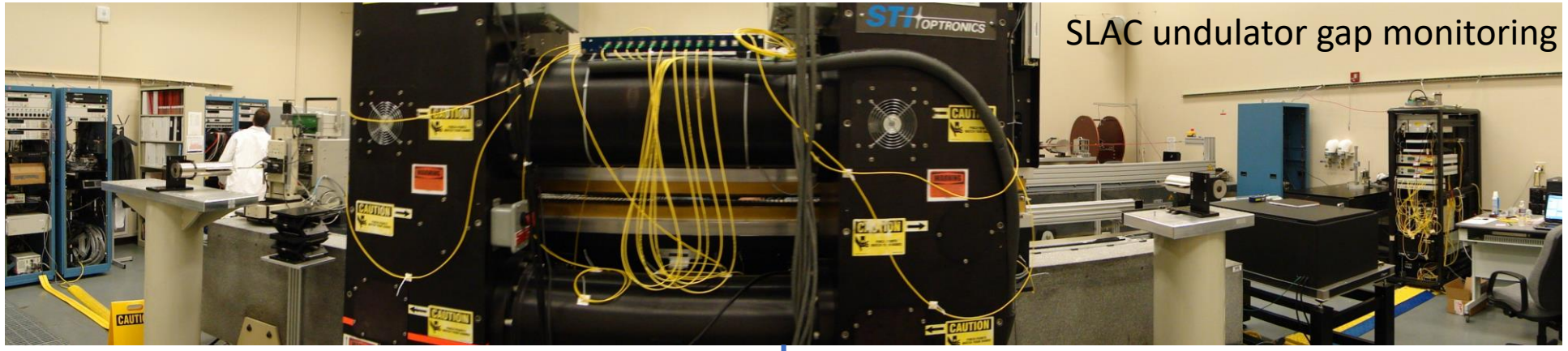
CERN developed it's own FSI system based on older & cheaper FSI versions from Oxford as the commercial version deemed too expensive.

Prototype Setup



Historic origins





Linear Collider Alignment and Survey seed corn for ground motion, stabilisation and alignments at ILC ➔ FSI technology Mark-II

STFC withdraws from ILC
WP6 terminates prematurely

1993 ATLAS SCT alignment system
Oxford FSI technology Mark-I

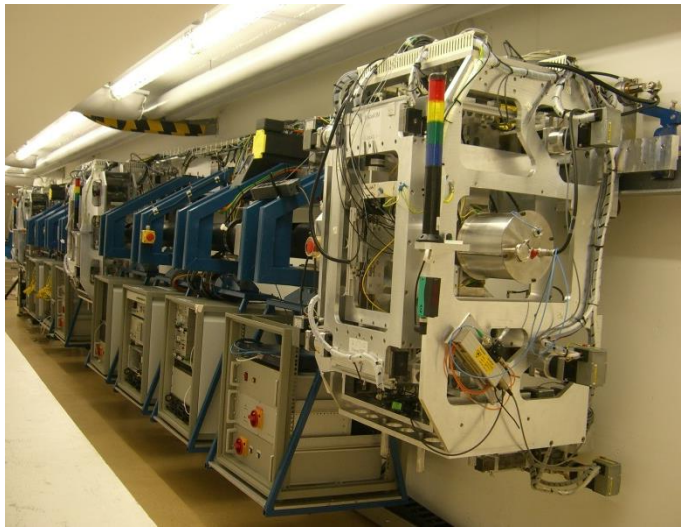
2003

2004 LC-ABD WP6

2008 2009

2010

2013 EPSRC-NPL-ETALON-JAI
AMULET = general purpose absolute distance measurement system for laser tracers



Robotic Tunnel Reference Surveyor (ILC @ DESY)

CAOX: geodetic network software at Petra-III survey network.

Reichold meets Schwenke CEO Etalon