Geodetic Infrastructure & Alignment - Planning and Studies

Mark JONES, CERN
Content

• FCC-ee Planning, Requirements & Constraints
• Provisional Survey Working Parameters
• Position Monitoring and Alignment System
• Geodetic Infrastructure
Planning, Requirements and Constraints
FCC integrated project technical schedule

- **Project preparation & administrative processes, Funding & governance strategy**
- **Permissions**
- **Geological investigations, infrastructure detailed design and tendering preparation**
- **Tunnel, site and technical infrastructure construction**
- **FCC-ee accelerator R&D and technical design**
- **FCC-ee accelerator construction, installation, commissioning**
- **FCC-ee detector technical design, collaborations**
- **FCC-ee detector construction, installation, commissioning**
- **Superconducting wire and high-field magnet R&D**
- **FCC-hh accelerator construction, installation, commissioning**
- **FCC-hh accelerator R&D and technical design**
- **FCC-hh detector R&D, technical design**
- **FCC-hh detector construction, installation, commissioning**
- **SC wire and 16 T magnet R&D, model magnets, prototypes, prototypes**
- **16 T dipole magnet series production**
- **FCC-ee dismantling, CE infrastructure adaptions FCC-hh**

FCC integrated project plan is fully integrated with HL-LHC exploitation and provides for seamless further continuation of HEP in Europe.

M. Benedikt

Overview Future Circular Colliders, EPPSU, Granada

<table>
<thead>
<tr>
<th>Project</th>
<th>Start construction</th>
<th>Start Physics (higgs)</th>
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<tbody>
<tr>
<td>FCC-ee</td>
<td>2029</td>
<td>2039 (2044)</td>
</tr>
</tbody>
</table>

D. Schulte

27.06.2019

M. Jones

Geodetic Infrastructure and Alignment

FCC Week 2019
System Requirements

- **FCC-ee**
  - Main Ring
  - Booster Ring

- **Smallest Misalignment Tolerance**
  - Values to Confirm
    - Quadrupoles and Sextupoles
    - FCC-ee Main Ring: 100 μm over ~100 m
    - Booster Ring: 150 μm
**FCC-ee Operational Constraints**

- **Winter Shutdown**
  - 12 to 20 wks
- **20 days Machine Development / yr**
- **11 days for Technical Stops**
- **Long Shutdown after 9 years**

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A. Niemi

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**FCC-ee Operation Timeline**

<table>
<thead>
<tr>
<th>shutdown</th>
<th>no. cryomodules</th>
<th>length of shutdown</th>
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<tr>
<td>shutdown 1</td>
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<td>shutdown 3</td>
<td>10 CM</td>
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<td>shutdown 4</td>
<td>26 CM</td>
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<td>shutdown 5</td>
<td>21 CM</td>
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<td>shutdown 6</td>
<td>42 CM</td>
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<td>shutdown 7</td>
<td>30 CM</td>
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<td>shutdown 8</td>
<td>30 CM</td>
<td>15 weeks</td>
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<tr>
<td>long shutdown</td>
<td>104 CM</td>
<td>1 year</td>
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<tr>
<td>shutdown 11</td>
<td>39 CM</td>
<td>17 weeks</td>
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<tr>
<td>shutdown 12</td>
<td>-</td>
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<tr>
<td>shutdown 13</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>shutdown 14</td>
<td>-</td>
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</tbody>
</table>
Other Constraints

• Significant tunnel / ground motion possible (>1 mm / year in LHC)
• Maintenance Access
  • Beamline elements
  • Position Monitoring and Alignment System
Provisional Survey Working Parameters
Interpretations & Assumptions! To Confirm!!

• Tunnel Alignment Precision Requirement
  • Main Ring: ~30 μm @ 1σ
  • Booster Ring: ~50 μm @ 1σ

• Quadrupoles and Sextupoles
  • Assembled on a Single Girder

• Frequent position monitoring required

• Re-alignment/Smoothing at least 1 / year
  • Main Beam arcs => ~12000 beamline modules
  • Booster arcs => ~10000 beamline modules
Provisional Survey Working Parameters

Interpretations & Assumptions! To Confirm!!

• Limited time for Survey tunnel activities
  • During both installation and operation
• Maintenance Access
  • Cannot disturb any Survey Tunnel Reference Infrastructure
• CDR Position Monitoring and Alignment Solution
  • Based on design for CLIC
  • Consequences for Accelerator Installation
  • Consequences for Geodesy
Initial Survey Planning

Costing → Planning

<table>
<thead>
<tr>
<th>COSTING CHART</th>
<th>Task Name</th>
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<tbody>
<tr>
<td>1. <strong>Consolidation and Development</strong></td>
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<td>1.1</td>
<td>CERN Reference Systems</td>
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<tr>
<td>1.2</td>
<td>Mathematical Modelling</td>
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<td>1.3</td>
<td>Gravity Field Modelling</td>
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<td>1.4</td>
<td>Software and Database Development</td>
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<td>1.5</td>
<td>Infrastructure Conceptual Designs</td>
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<td>2. <strong>Survey</strong></td>
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<td>2.1</td>
<td>Surface Geodetic Reference Network Concept</td>
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<td>FCC Map Projection Selected</td>
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<td>Geoid Model Precision Simulations</td>
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<td>3. <strong>Geodetic Engineering</strong></td>
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<td>Surface to Tunnel Transfer Technology</td>
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<td>Technology Review</td>
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<td>Prototype Proposals</td>
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<td>Prototype Development</td>
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<td>3.5</td>
<td>Prototype Testing</td>
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<td>4. <strong>Deflectionmeter</strong></td>
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<td>Convexity</td>
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<td>4.2</td>
<td>Test and Evaluate</td>
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<td>5. <strong>ICT Needs Analysis</strong></td>
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<td>5.1</td>
<td>Long Distance Control Baseline Conceptual Design</td>
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<td>Azimuth Control Baseline Conceptual Design</td>
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<td>6. <strong>SU Integration of G.S. Monitoring Sensors Study</strong></td>
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<td>7. <strong>FCC on Alignment System Conceptual Design</strong></td>
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<td>7.1</td>
<td>Civil engineering guidelines for survey constraints</td>
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<td>7.2</td>
<td>Simulate effect on alignment of Tunnel Reference Point errors</td>
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<td>8. <strong>Tunnel Geodetic Reference Network Concept</strong></td>
<td></td>
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<tr>
<td>9. <strong>Position Monitoring &amp; Alignment System (PMAS) Concept</strong></td>
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<td>9.1</td>
<td>Requirements/Constraints Analysis</td>
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<td>Study Planned and Implemented Alignment Systems</td>
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<td>9.3</td>
<td>Main Ring PMAS Concept</td>
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<td>9.4</td>
<td>Booster Ring PMAS Concept</td>
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<td>ND Final Focus PMAS Concept</td>
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<td>9.6</td>
<td>PMAS Remote Maintenance Concept</td>
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<td>10. <strong>Injection and Transfer Lines (PMAS) Concept</strong></td>
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<tr>
<td>11. <strong>Geodesy</strong></td>
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<td>11.1</td>
<td>Surface Geodetic Reference Network (SGRN)</td>
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<td>SGRN Technical Design and Specs</td>
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<td>SGRN Procurement Preparation</td>
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<td>SGRN Instrumentation Reception</td>
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<td>11.6</td>
<td>SGRN Instrument Calibration</td>
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<td>11.7</td>
<td>Build SGRN</td>
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<tr>
<td>11.8</td>
<td>Measure SGRN</td>
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</tbody>
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Geodetic Infrastructure and Alignment
FCC Week 2019
Position Monitoring and Alignment System
FCC-ee Position Monitoring & Alignment

- Concept based on design for CLIC
  - Full Remote Position Monitoring and Alignment System
  - Wire Position sensors
  - Hydrostatic Levelling sensors
  - Motorised positioning system

Design for CLIC

Articulation point
WPS sensor
Metrological plate (MRN)

Master cradle:
- 2 WPS
- 3 linear actuators

Slave cradle:
- 2 WPS
FCC-ee Position Monitoring & Alignment

- Precision specifications
- Smoothing Time Constraints
  - Continuous Monitoring
  - Automated remote re-alignment with continuous feedback
- Metrology precisions for ~6 m long elements
- Tunnel Reference Infrastructure
  - Space requirement in curved tunnels
  - Full remote maintenance (HL-LHC developments + … ??)
Alternative -Alignment Train

• Precision specifications
  • Simulations with available measurement instruments/sensors
  • Measurement platform to be developed
  • Vertical measurement

• Smoothing Time Constraints
  • Currently in LHC the reference wire is installed manually
  • Re-positioning will have to be automated
  • Smoothing process typically => 2-3 iterations
  • 4 weeks smoothing => currently ~40 alignment trains

• Tunnel Reference Infrastructure
  • Space requirement in curved tunnels
  • Motorised positioning system, remote maintenance
FCC Integrated Project Schedule

Alignment

- Tunnel Geodetic Reference Network
- As-Built Surveys
- Gravity Field Measurements
- Marking Out
- Monitoring & Alignment System
  - Tunnel Reference Infrastructure
  - Position Monitoring instrumentation
  - Position Alignment equipment

Civil Engineering Works Start
C.E. Construction Invitation to Tender Start
Injector Installation Start
FCC Installation Start

<table>
<thead>
<tr>
<th>Week</th>
<th>Activity</th>
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<tbody>
<tr>
<td>1</td>
<td>LHC run 3</td>
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<tr>
<td>2</td>
<td>LS 3</td>
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<tr>
<td>3</td>
<td>LHC run</td>
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<tr>
<td>4</td>
<td>LS4</td>
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<td>5</td>
<td>LHC run 5</td>
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<td>6</td>
<td>LS5</td>
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<td>7</td>
<td>LHC run 6</td>
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<td>8</td>
<td>Project preparation &amp; administrative processes Funding &amp; governance strategy</td>
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<td>Permissions</td>
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<td>10</td>
<td>Geological investigations, infrastructure detailed design and tendering preparation</td>
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<tr>
<td>11</td>
<td>C.E. Construction Invitation to Tender Start</td>
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<tr>
<td>12</td>
<td>Tunnel, site and technical infrastructure construction</td>
</tr>
<tr>
<td>13</td>
<td>FCC Installation</td>
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<tr>
<td>14</td>
<td>Alignment</td>
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<tr>
<td>15</td>
<td>Civil Engineering Works</td>
</tr>
<tr>
<td>16</td>
<td>Injector Installation</td>
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<tr>
<td>17</td>
<td>FCC Installation</td>
</tr>
<tr>
<td>18</td>
<td>Alignment</td>
</tr>
</tbody>
</table>
Position Monitoring and Alignment System

Main Ring and Booster Ring

1. LHC run 3
2. LS 3
3. LHC run
4. LS4
5. LHC run 5
6. LS5
7. LHC run 6

- Project preparation & administrative processes
- Funding & governance strategy
- Permissions
- Geological investigations, infrastructure detailed design and tendering preparation
- C.E. Construction Invitation to Tender
- FCC Installation Start
- Injector Installation Start
- Civil Engineering Works Start

FCC Tunnel Reference
- Infrastructure Installation
- Start

FCC-ee accelerator R&D and technical design
- Detector R&D and concept development
- FCC-ee detector technical design, collaborations
- FCC-ee detector construction, installation, commissioning

Y_{14}
Position Monitoring and Alignment System

Main Ring and Booster Ring

Accelerator Information Required
- Theoretical Design
- FCC-ee Integration Model
- Metrology & Alignment Precisions

To be developed
- Refined Gravity Field Model
- Tunnel Reference Infrastructure
- Beamline Elements
- Position Monitoring System
- Positioning System
- Control, Data Management and Data Processing Systems
Position Monitoring and Alignment System

Main Ring and Booster Ring

FCC Week 2019

Injector Installation Start

FCC Installation Start

FCC Tunnel Reference

Infrastructure Installation Start

FCC ee accelerator R&D and technical design

FCC ee detector technical design, collaborations

Detector R&D and concept development

FCC ee detector construction, installation, commissioning

FCC ee accelerator construction, installation, commissioning

Geological investigations, infrastructure detailed design and tendering preparation

Tunnel, site and technical infrastructure construction

Project preparation & administrative processes

Funding & governance strategy

Permissions

LHC run 3

LS 3

LHC run 4

LS 4

LHC run 5

LS 5

LHC run 6
Position Monitoring and Alignment System

Main Ring and Booster Ring Preparatory Activities

Injector Installation Start
FCC Installation Start
Market Study/Survey and Invitation to Tender Start
Procurement and Instrumentation Control Start
FCC Tunnel Reference Start
Infrastructure Installation

Needs Analysis
Pre-Prototype Studies Start
Prototype Development and Tests Start
Pre-Series Upgrade and Tests Start
Technical Design & Specifications Start

Y_1
Y_2
Y_3
Y_6
Y_9
Y_11
Y_12
Y_14
Y_15
Y_16
Y_17
Y_18

FCC Week 2019

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Geodetic Infrastructure and Alignment
FCC Week 2019
Position Monitoring and Alignment System

Main Ring and Booster Ring
Installation Activities

- Tunnel Geodetic Reference Network
- Marking Out
- Gravity Field Measurements
- Install Tunnel Infrastructure
- Position Monitoring and Alignment System Infrastructure Installation
  - Metrology Reference Network
  - Monitoring System Infrastructure
  - Positioning System Infrastructure
- Install Beamline Elements
- Position Monitoring and Alignment System Installation
  - Monitoring Sensors and Commissioning
  - Positioning Actuators and Commissioning
- Align Beamline Elements
Geodetic Infrastructure
FCC Integrated Project Schedule

Geodetic Infrastructure

• Surface Geodetic Reference Network
• Reference Systems
• Precision Gravity Field Model
• R&D of Geodetic Instruments
• Instrument Control Calibration, and Test Facilities
• Geodetic Transformation Software
Geodetic Infrastructure

• Starting almost from scratch
  • Most geodetic infrastructure dates back to LEP
  • Established for the current CERN site ~100 km$^2$
  • FCC site covers ~1000 km$^2$
• CERN not currently equipped for this activity
• CERN surveyors
  • Establish control infrastructure for C.E.
  • Contributions and Controls for C.E. Tender Documents
Geodetic Infrastructure & Activities

Geodesy
- CERN / FCC Reference Systems
- Geodetic Surface Reference Network
- Gravity Field Model

Geodetic Engineering
- Control Baselines for Azimuths and Distances
- Instrument Control, Calibration and Test Facility
- Mathematical Modelling
- Precision surface to tunnel transfer technology

C.E. Project
- C.E. Invitation to Tender Docs. - Contributions & Controls
- Geodetic Transformation Software Development
- Integration of C.E. monitoring sensors in Survey reference networks
Geodetic Reference Infrastructure for C.E. Construction

- Civil Engineering Works Start
- C.E. Construction Invitation to Tender Start
- Geodetic Infrastructure Ready
- Injector Installation Start
- FCC Installation Start
- Project preparation & administrative processes
- Funding & governance strategy
- Geological investigations, infrastructure detailed design and tendering preparation
- FCC-ee accelerator R&D and technical design
- Detector R&D and concept development
- FCC-ee accelerator construction, installation, commissioning
- FCC-ee detector technical design, collaborations
- Tunnel, site and technical infrastructure construction

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Geodetic Infrastructure and Alignment
FCC Week 2019
Geodetic Infrastructure Work Y3-Y7

- Hiring
- Invitation to tender
- Procurement
- Land
- Equipment
- Instruments
- Training
- Prototypes
- Mathematical Models
- Development
- Construction
- Testing
- Controls
- Installation
- Calibration
- Reception
- Site Location
- Specifications
- Technical Design
- Analysis
- Software Applications
- Data Management
- Commissioning
- Measurement Campaigns
- Land Access
Reference Point Co-ordinates for C.E. Construction

Accelerator Information Required
- Theoretical Design
- FCC-ee Integration Model
- Metrology & Alignment Precisions

To be developed
- Geodetic Surface Reference Network
- Mathematical Reference Systems and Transformation Algorithms
- Gravity Field Model
- Geodetic Transformation Software
Reference Point Co-ordinates for C.E. Construction

Accelerator Information Required
- Theoretical Design
- FCC-ee Integration Model
- Metrology & Alignment Precisions

To be developed
- Geodetic Surface Reference Network
- Mathematical Reference Systems and Transformation Algorithms
- Gravity Field Model
- Geodetic Transformation Software
FCC Integrated Project Schedule

Geodetic Infrastructure

- Ambitious timeline
- Expert consultants needed
- Numerous design concepts to develop ...
- and implement
Other studies required too

• FCC-ee MDI
• Injectors: Linac, Damping Ring, Pre-Booster, Transfer Lines
• Marking out > 100 km tunnel in Y13
  • Manually like the LHC? 😞
• Pre-aligning supports / positioning systems
  • Faster, automated methods? Y14
Conclusions

• Position Monitoring and Alignment System
  • Need to start work on attributing the misalignment budget?
  • Start studies for the technical design solution
    • Research and Development of potential solutions
      • 16 years before tunnel installation starts
  • Significant time may be required prior to installing a beamline element
Conclusions

- Geodetic Infrastructure
  - Geodesy akin to Geology
    - To do established before Civil Engineering starts
  - Geodetic infrastructure
    - To be in place before Y8
    - Design concepts to be established
    - Instruments to develop and test
- Some budget available already
- Ambitious timelines for both Geodesy and Alignment!
Thank you for your attention
Conceptual Design Stage

• Gravity Field Study
  • Measurement Requirements as a function of Alignment Precision
  • Pre-prototype instrument tested and evaluated
  • (Differential Geodetic Interferometric) Deflectometer
FCC-ee Geoid Model

• Analysis, Modelling (Y7)
  (+ Database and Software Implementations)
• Measurements (Y5 & Y6)
  • Astro geodetic measurements (2 years)
    • 5 x Zenith Cameras
• Purchase 5 Zenith Cameras (Y3 & Y4)
  • Production time
    • ~1.5 years
  (+ Specifications, Procurement and Land Access)
Integration