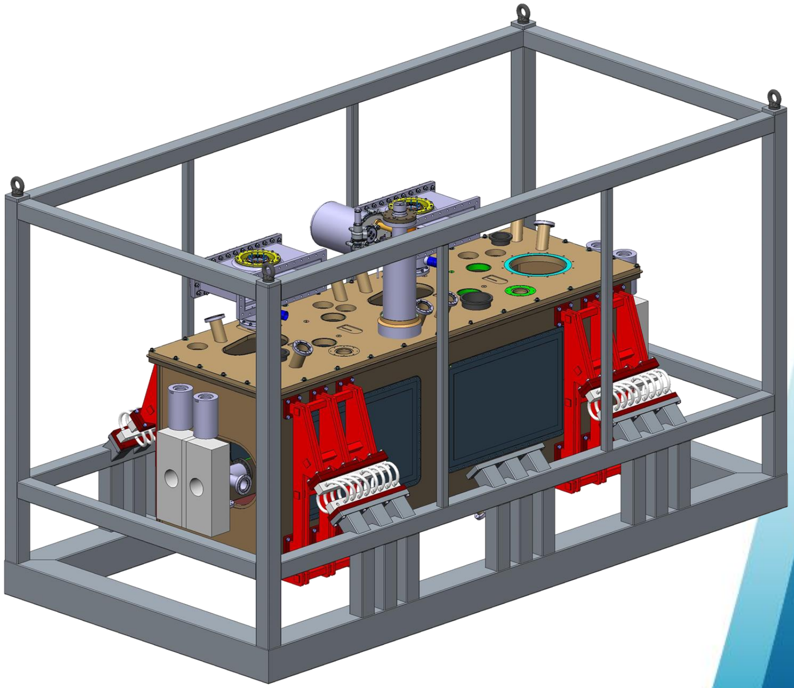
HiLumi
HL-LHC PROJECT

Transport Aspects



Edward Jordan

Crab Cavity International Review – CERN – 20th June

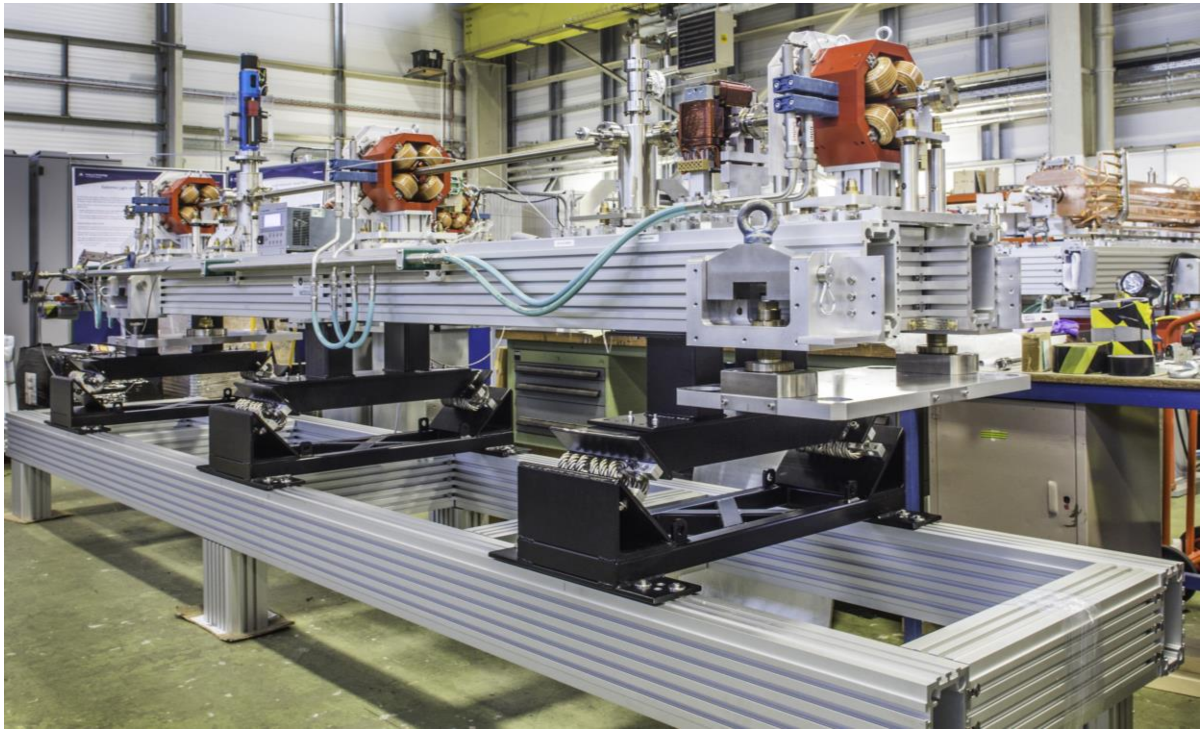
Background

- Anti Shock Frame - Requirement:
  - "A suitable support shall be designed to safely transport the Cryomodule from assembly premises to CERN where it will be tested and installed. The solution shall reduce all forms of vibration and shock loading to **as low as reasonably practicable**."
- This presentation will focus on mechanical solution to **reduce shock loading**.

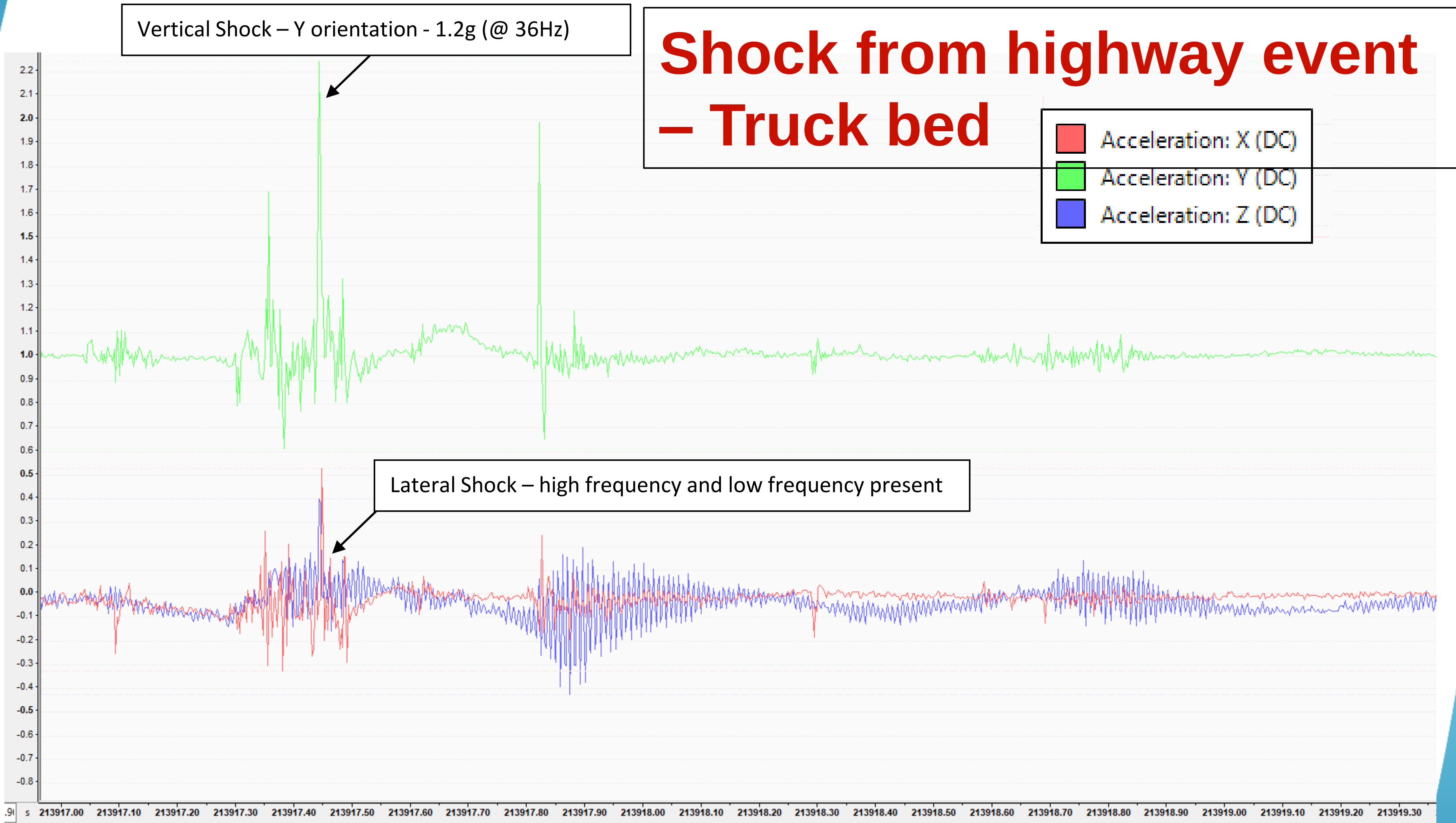
STFC Experience - Wire rope isolators

- Proven to reduce shock and random vibration transmission
- Experience (and Data) gained at Daresbury through shipment of 12 modules to ELI-NP in Romania

Note: isolators should be at COM height for optimum performance, this position was a compromise to maximise the number of module per transport (i.e. up to 4 modules per trailer)

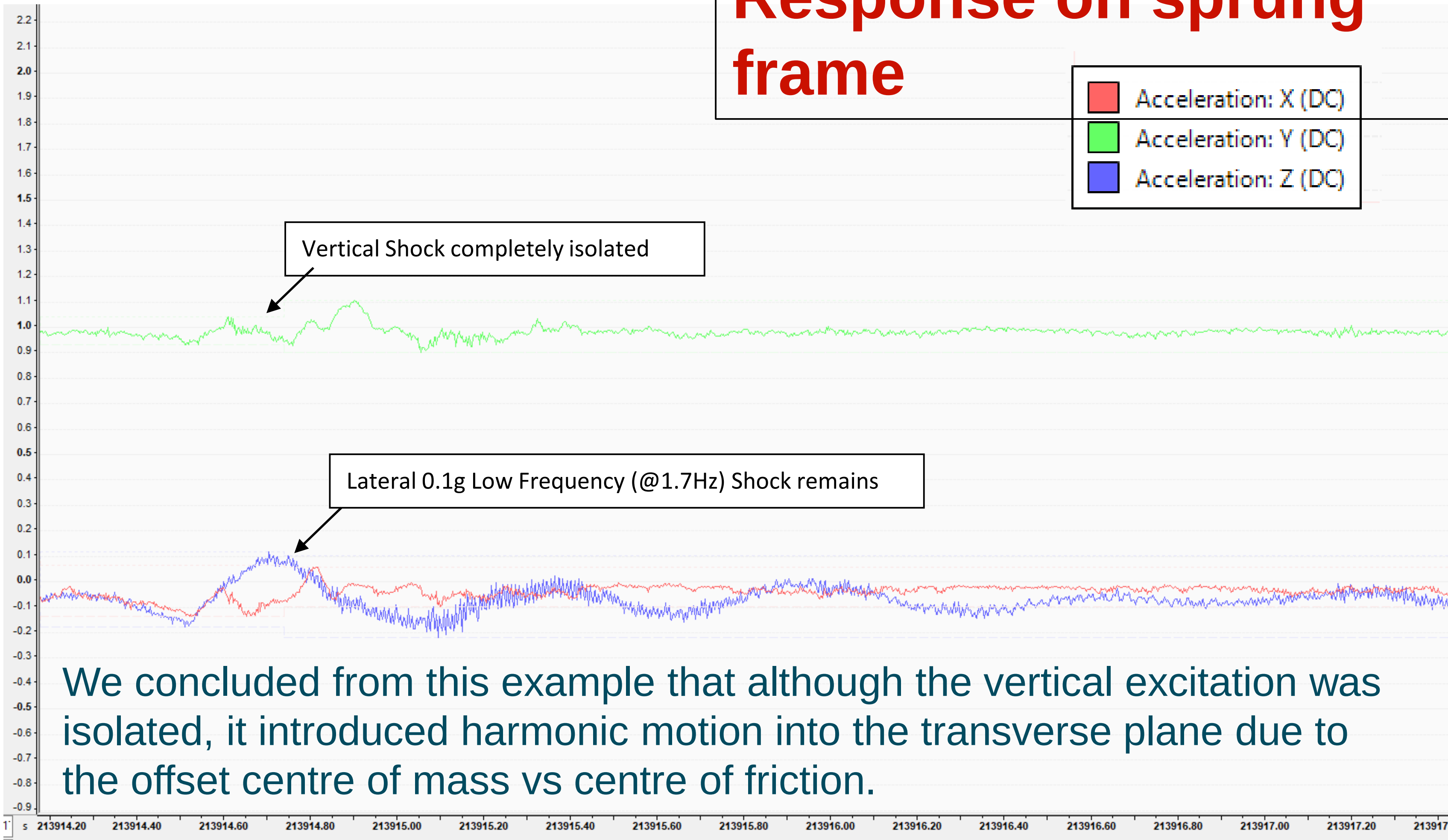


Vertical wire rope isolator performance



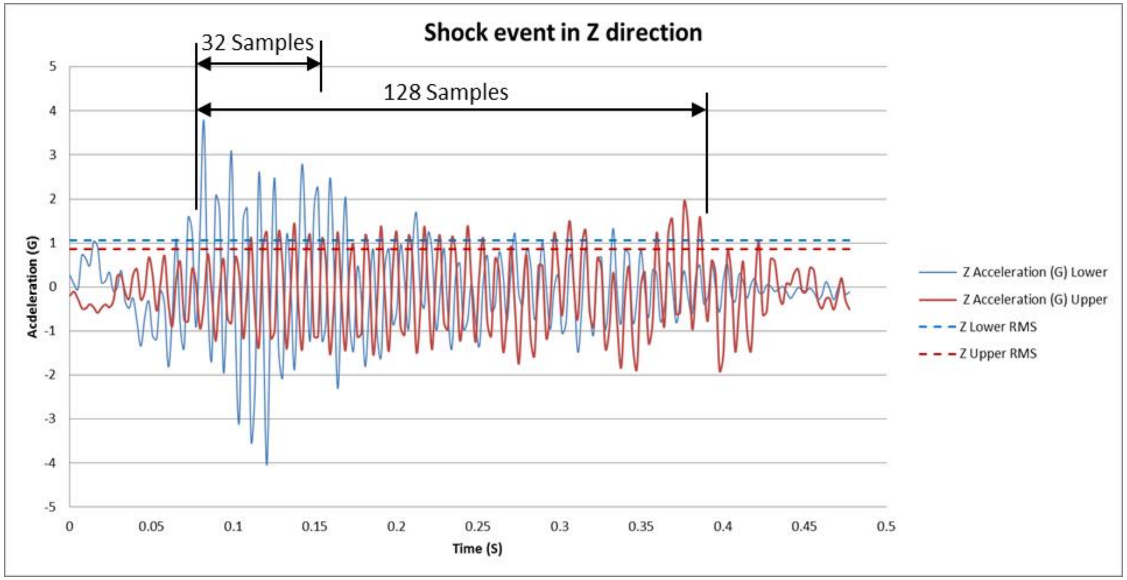
Vertical wire rope isolator performance

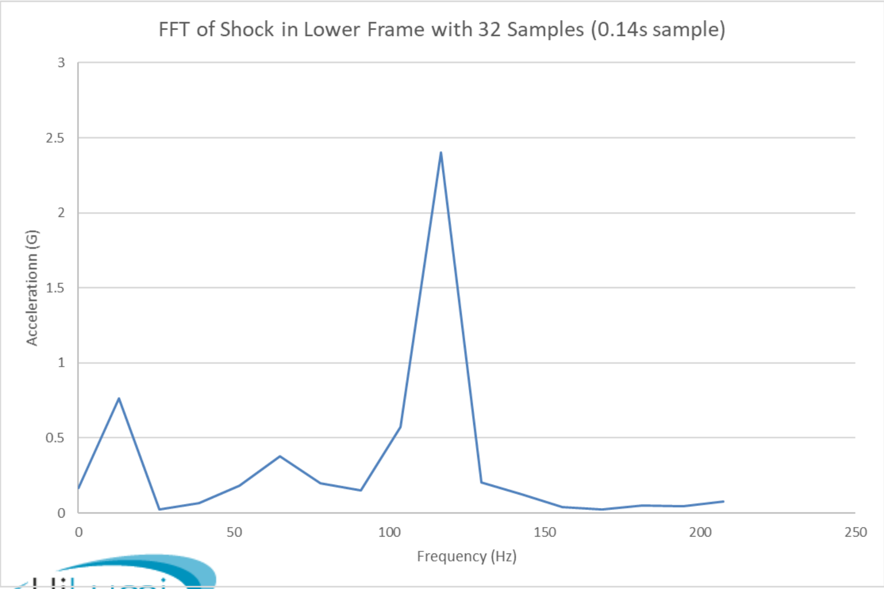
Response on sprung frame

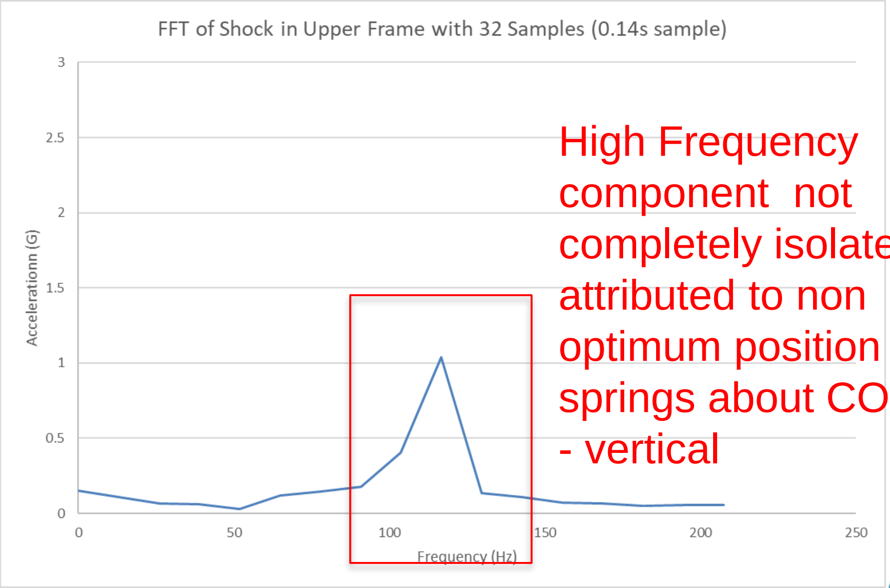


We concluded from this example that although the vertical excitation was isolated, it introduced harmonic motion into the transverse plane due to the offset centre of mass vs centre of friction.

Lateral wire rope isolator performance





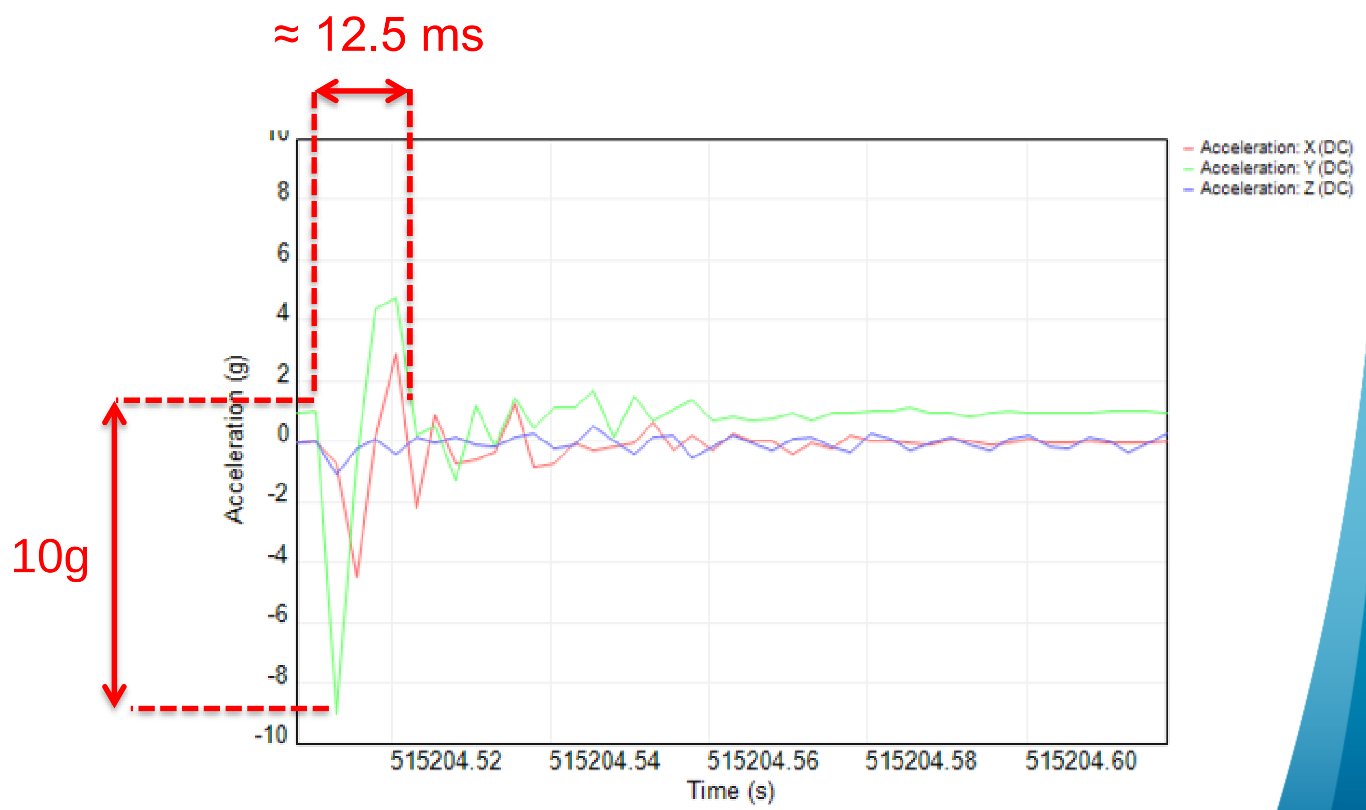


High Frequency component not completely isolated; attributed to non optimum position of springs about COM - vertical

Shock from lowering equipment onto floor (in Romania)

Reviewing data acquired when shipping normal conducting accelerators from Daresbury Lab to Magurele, Romania, a 10g shock can be seen over a time period of 12.5 ms, corresponding to frequency of approximately 80 hz.

This shock was observed when the equipment **was removed from its anti-shock frame** and lowered onto the ground (i.e. with **no wire-rope isolation**).

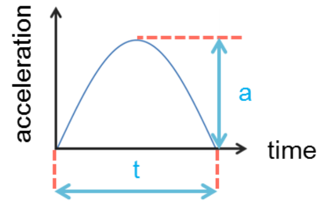


Mathematical Method for spring selection (1)

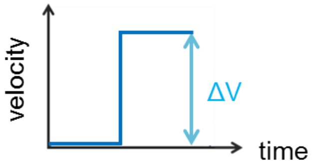
- **First - Verify spring can withstand shock load**

We calculate the input energy into the spring using one of 3 cases:

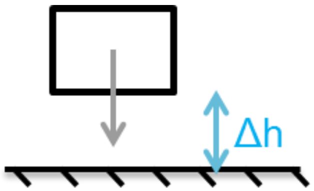
1. Semi-sinusoidal shock
   - $\Delta E = \frac{2}{\pi^2} * m * (a * t)^2$



2. Instantaneous velocity change
   - $\Delta\, E = \frac{1}{2} * m * \Delta V^2$



3. Drop height
   - $\Delta\, E = mg\Delta h$



If the energy input is lower than the maximum energy absorption of that spring, the spring can be used.

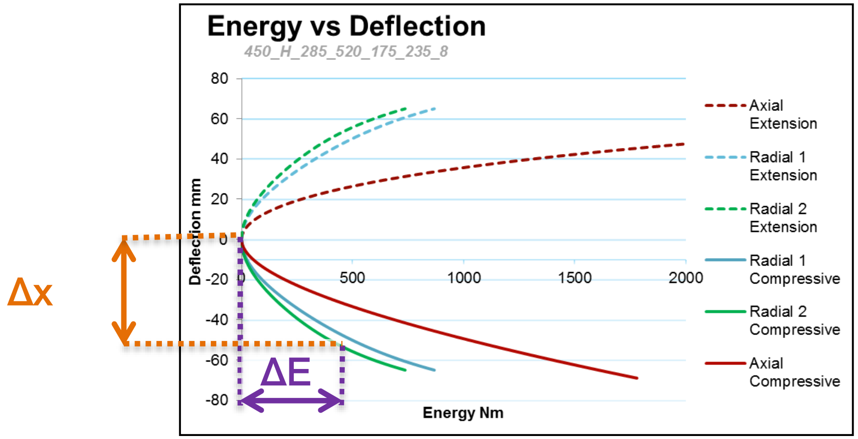
Mathematical Method for spring selection (2)

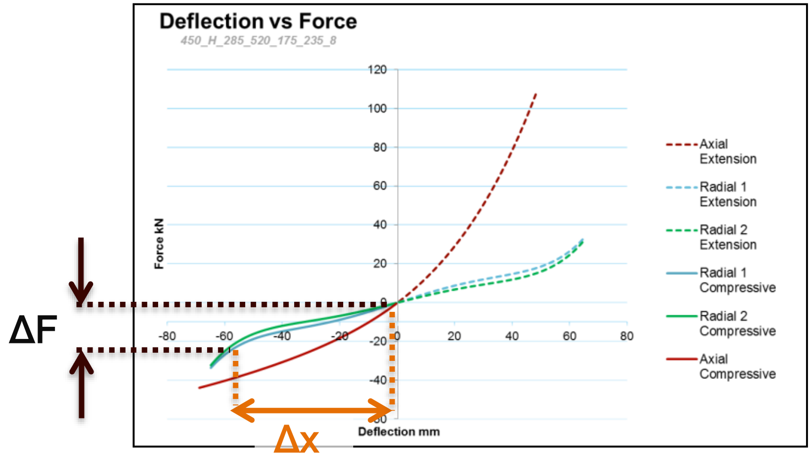
- **Second, derive transmitted force input onto Cryomodule from compressed spring by:**

$\Delta E \rightarrow \Delta x \rightarrow \Delta F$

- Using calculated energy change, look-up on spring energy curve to find equivalent spring deflection*.
- Using identified deflection, look-up on spring force curve to find equivalent spring force.
- Calculate acceleration applied onto load using equivalent reaction force

4. $$\frac{F}{m} = a$$





*Spring data acquired from product reseller.

Mathematical Model - Example

- Using shocks identified from data shown on pages 6,7,8:
  1. 1.2 g (@ 36 Hz) Vertical
  2. 10 g (@ 80 Hz) Vertical

Mass of Cryomodule is a primary variable!

Mass used = 3300kg

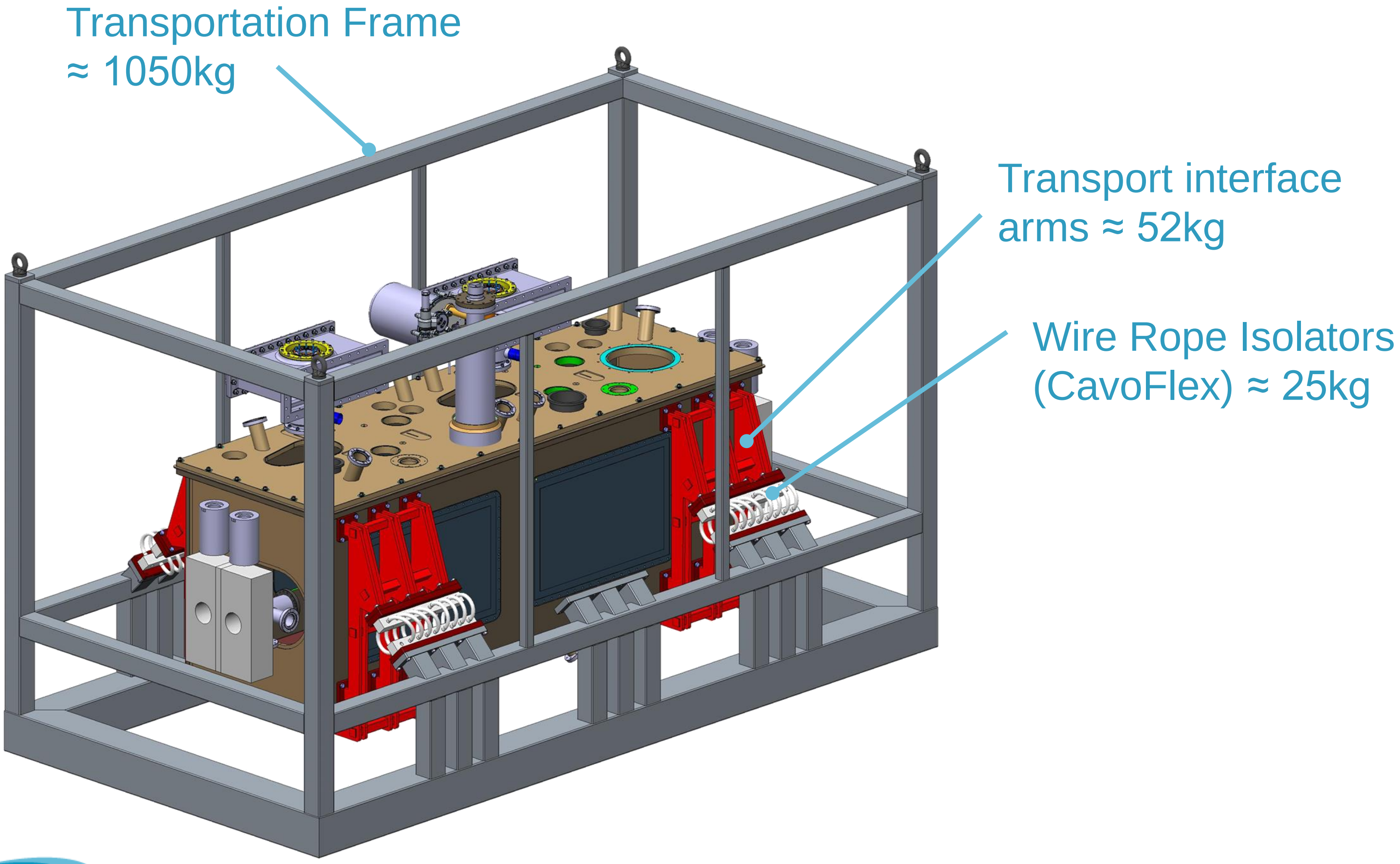
Case Load	Input Acceleration	Input Frequency	Output Acceleration	Acceleration Reduction	Stroke Utilised
	g	*Hz*	*g*	*%*	*%*
1	1.2	36	0.43	64	0.18
2	10	80	1.08	89	2.53

Reference Designs

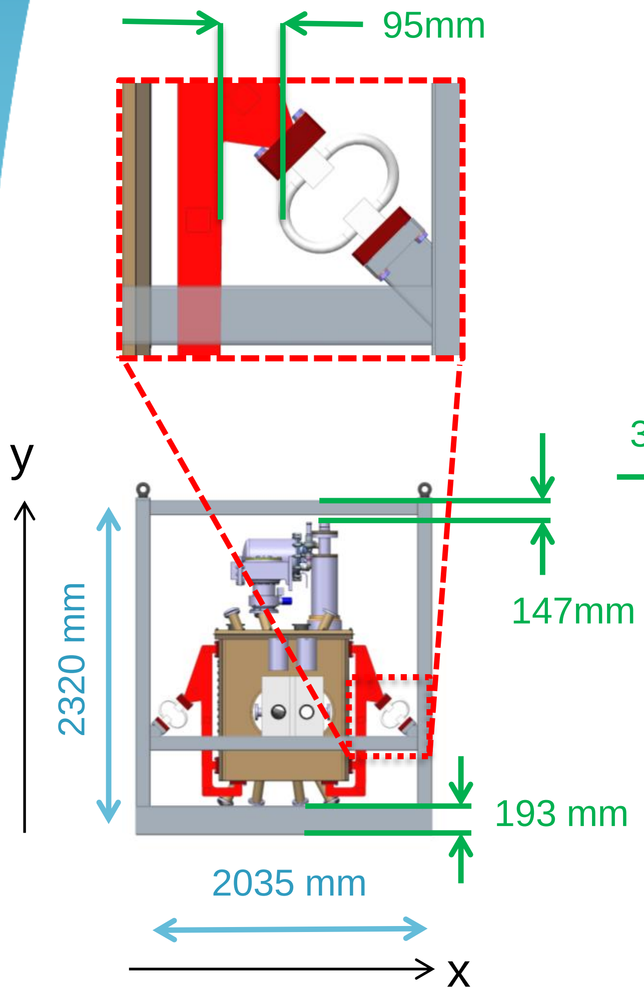
SLAC CM transportation to DL (2013)

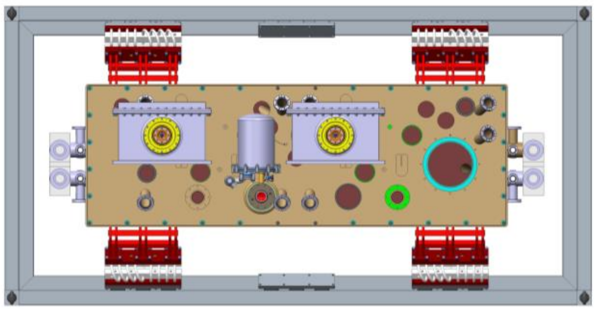
ELI Accelerating Modules to Romania (2017)

Concept Design

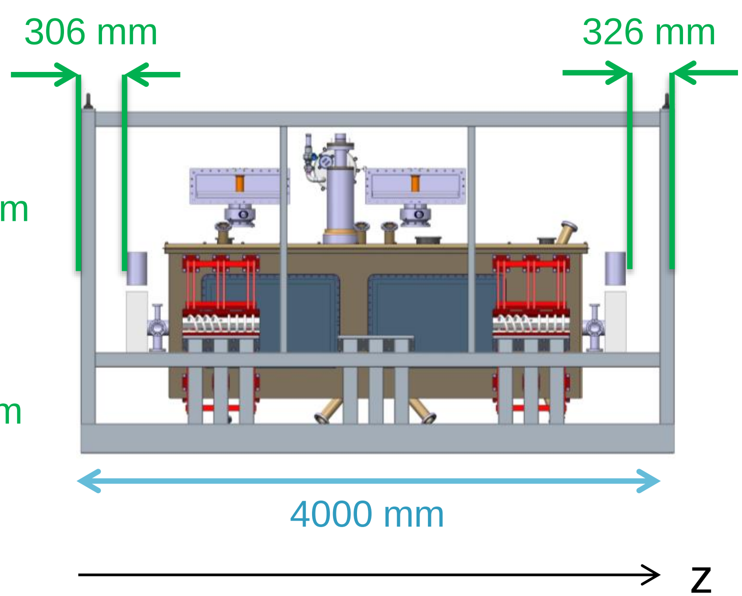


Critical Dimensions

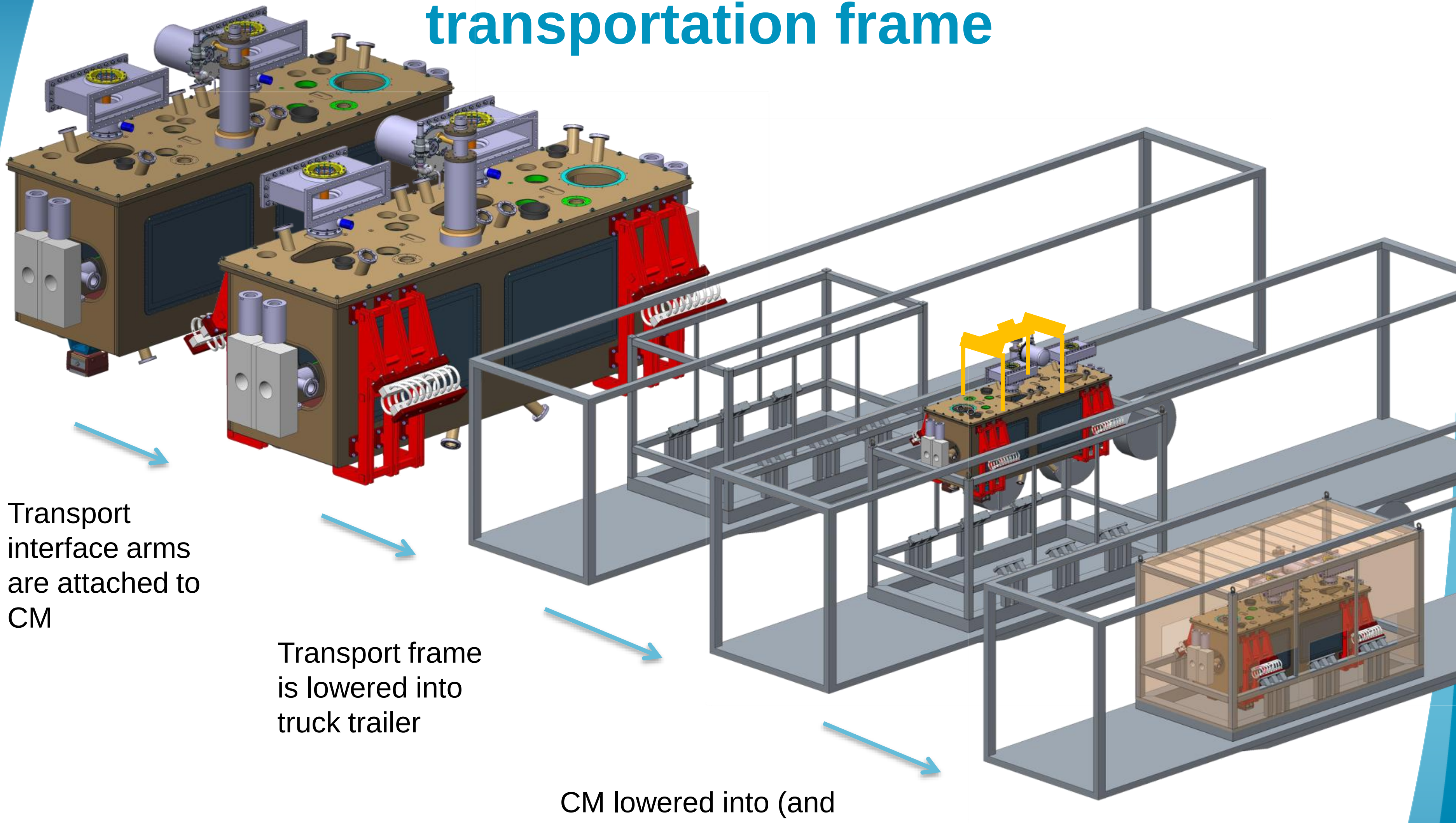




Direction	Clearance
x	95mm + 95mm
y	193mm + 147mm
z	306mm + 326mm



Assembly procedure – Cryomodule into transportation frame



Transport interface arms are attached to CM

Transport frame is lowered into truck trailer

CM lowered into (and fastened) to transport frame.

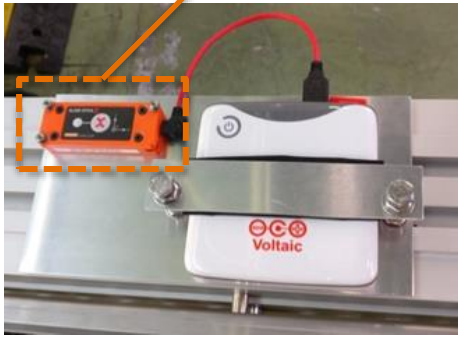
Wooden panels fixed to exterior

Instrumentation

The instrumentation will serve to verify the suitability of the frame design.

- Accelerometer – Slamstick with individual battery pack,
  - Sampling frequency at 400hz,
  - Aliasing effect at chosen sample rate to be investigated,

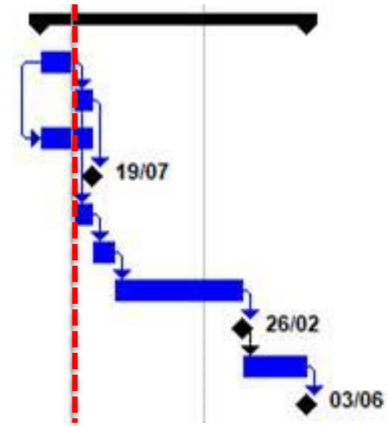
Mide Slam Stick X accelerometer
LOG-0002-100G-DC



- GPS tracking-
  - TO be discussed with haulage company to allow location accuracy of events during journey,
- Absolute distance measurement
  - Device to be investigated,

Transportation frame production planning

Transportation Frame Design and Manufacture	**250 days**	**Wed 01/05/19**	**Wed 03/06/20**
Transportation Frame Concept Design	1.5 mons	Wed 01/05/19	Wed 19/06/19
Analysis and Optimisation	1 mon	Wed 19/06/19	Fri 19/07/19
Development of Transportation Plan	2.5 mons	Wed 01/05/19	Fri 19/07/19
Cryomodule Transportation Review	0 days	Fri 19/07/19	Fri 19/07/19
Produce Transportation Frame Manufacturing Drawings	1 mon	Wed 19/06/19	Fri 19/07/19
Tender for Frame and Spring Procurement	1 mon	Fri 19/07/19	Mon 19/08/19
Manufacture Transportation Frame	6 mons	Mon 19/08/19	Wed 26/02/20
Transportation Frame Manufacture Complete	0 days	Wed 26/02/20	Wed 26/02/20
Transportation Frame Testing	3 mons	Wed 26/02/20	Wed 03/06/20
Transportation Frame Testing Complete	0 days	Wed 03/06/20	Wed 03/06/20



Today

Content of transport plan:

1. Transportation method
2. Cryomodule internal transportation tooling
3. Transportation frame
4. Loading procedure
5. Instrumentation and Visual Indicators
6. On departure: Cryomodule checks and evidence
7. On receipt: Cryomodule checks and evidence
8. Acceptance vs failure scenarios

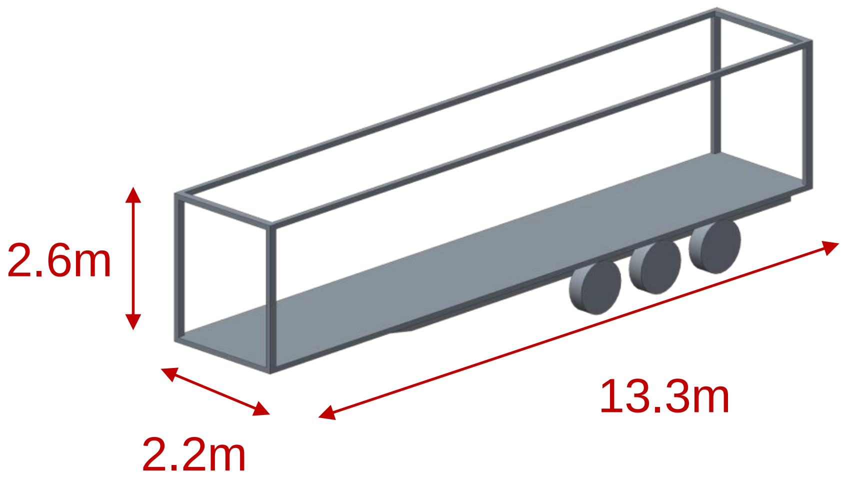
Note on testing:

- We plan to procure a concrete block with identical size, mass and mounting points as Cryomodule,
- Conduct on road testing to validate transportation frame performance,

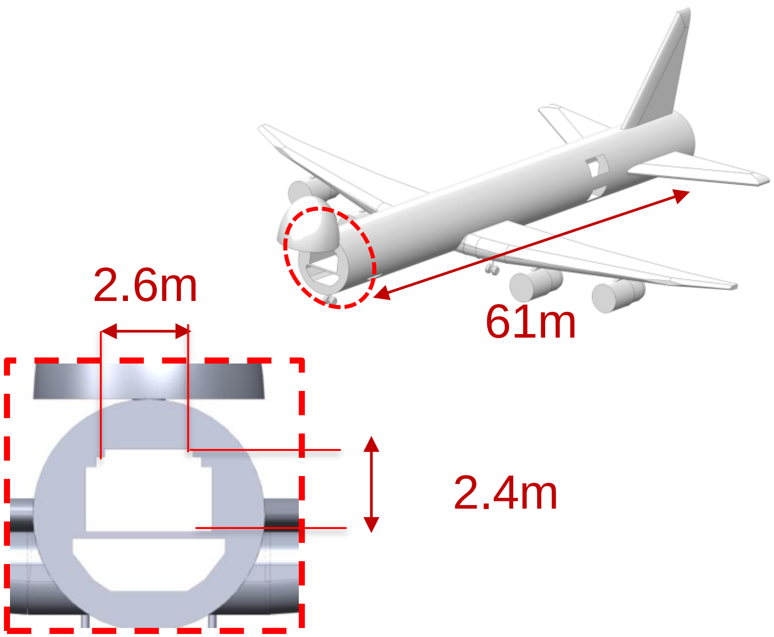
Thank you for your attention

Reference slides

Design envelope truck: 2.6m x 2.2m x 13.3m (HWL)



Design envelope 747 400F: 2.4m x 2.6m x 61m (HWL)



Design envelope combined: 2.4m x 2.2m x 13.3m (HWL)