Characterisation of autoclaved aerated concrete under shock loading using high frequency X-Ray radiography

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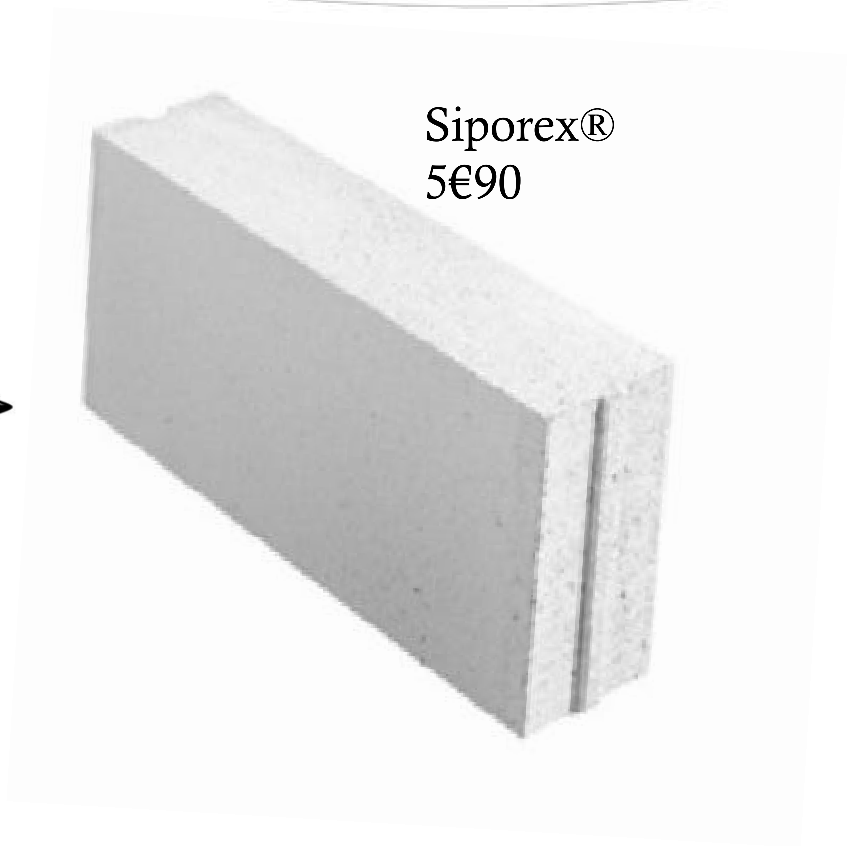
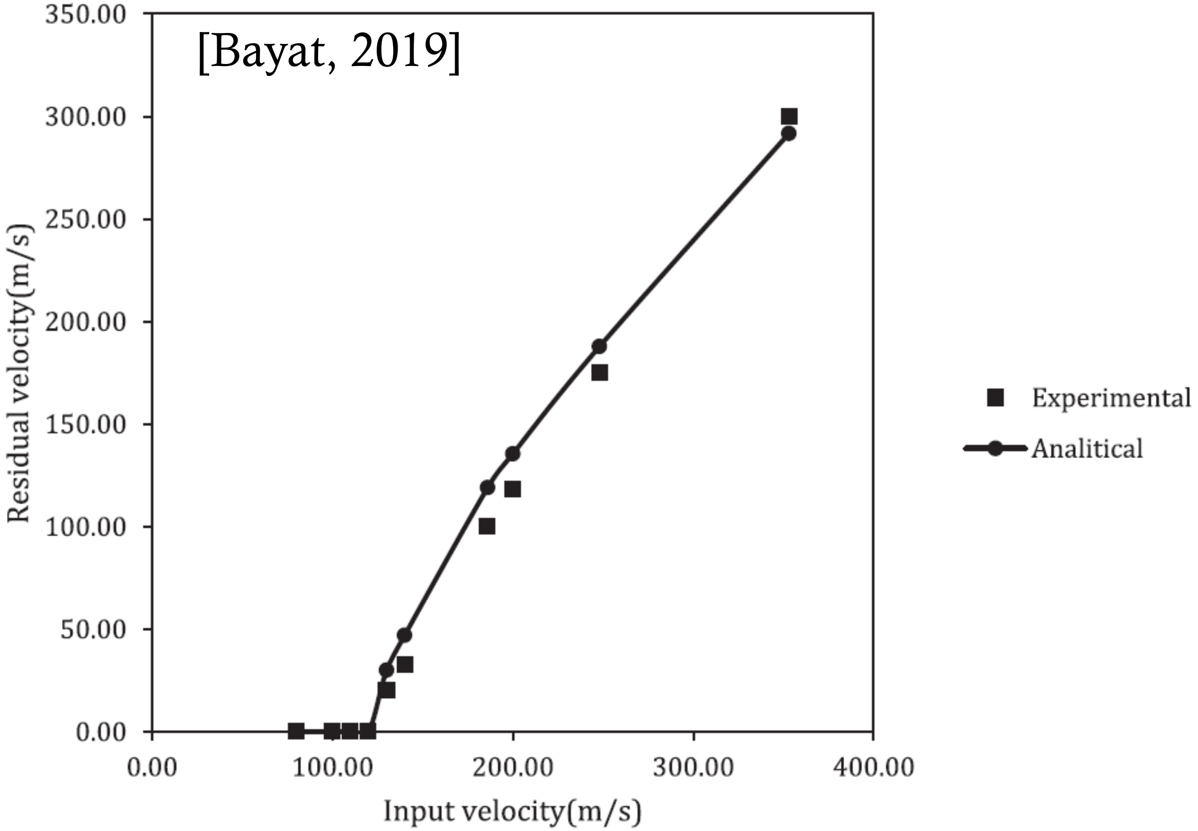
4th DYCOMAX, Thursday, the 12th of March

Why should we be interested by Autoclaved Aerated Concrete (AAC)?



ρ=550 kg/m^3, thickness 50 mm

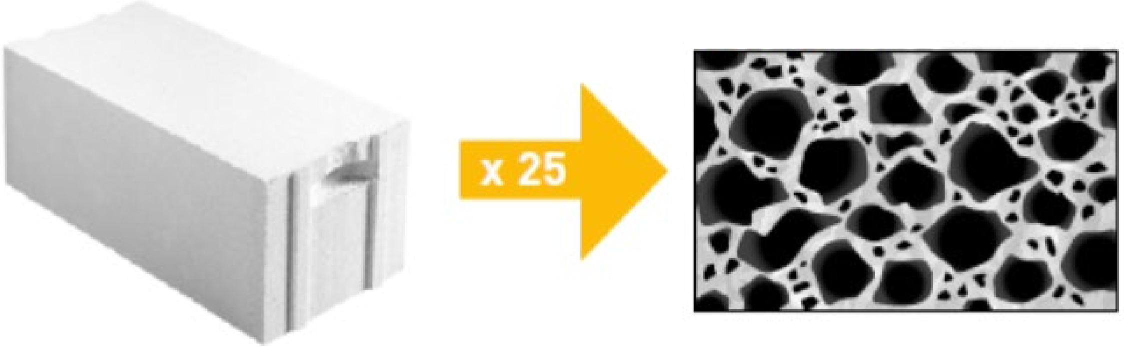


⇒ 50 mm thick Siporex stops projectiles at 120 m/s and slowens down by 50m/s at higher velocity

⇒ Good ability for mitigating the effects of ballistic & fragment impact.

Autoclaved Aerated Concrete (AAC)

- Insulating material
- Porous material
- Resistant to fire
- Refractory material
- Low impact on environment
- Low cost



Material description

- Autoclaved concrete manufactured by Xella® :
  1. Siporex
  2. Multipor
- Made of same components but different ratios
- Variation on density
- Different mechanical properties

Quantity	Multipor	Siporex
Density ρ	$115\ kg/m^3$	$550\ kg/m^3$
Young modulus E	0,6 GPa	2,74 GPa
Compressive strength RM	0,35 MPa	4,5 MPa

multipor

SIPOREX

Mechanical properties under shock loading?

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Summary

- Plate impact Setting at ESRF
- Data processing with Python
- Analytical analysis

Plate-impact experiment setup

- Plate-impact experiment
- 3 velocities for each AAC
- X-Ray recording

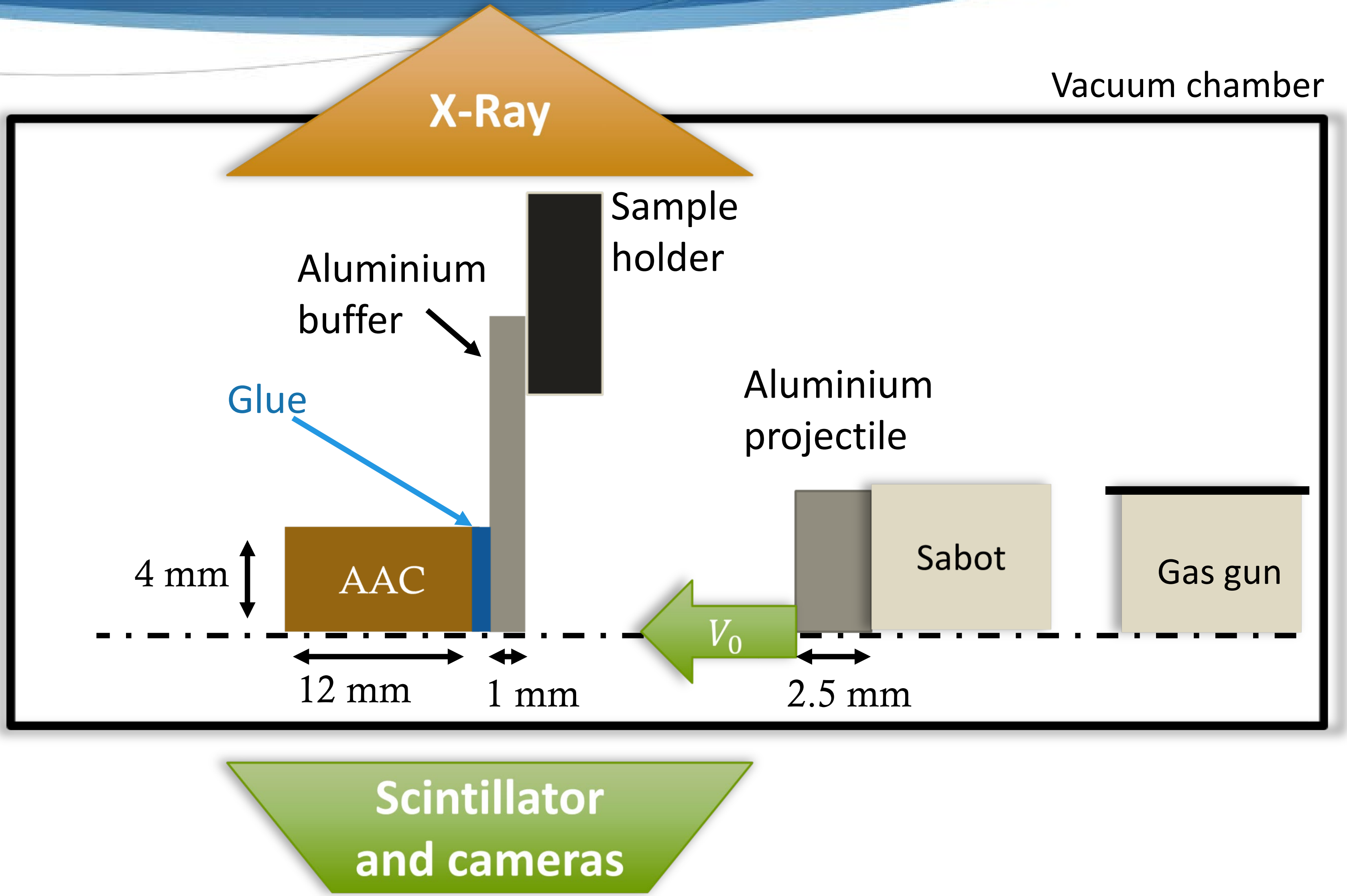
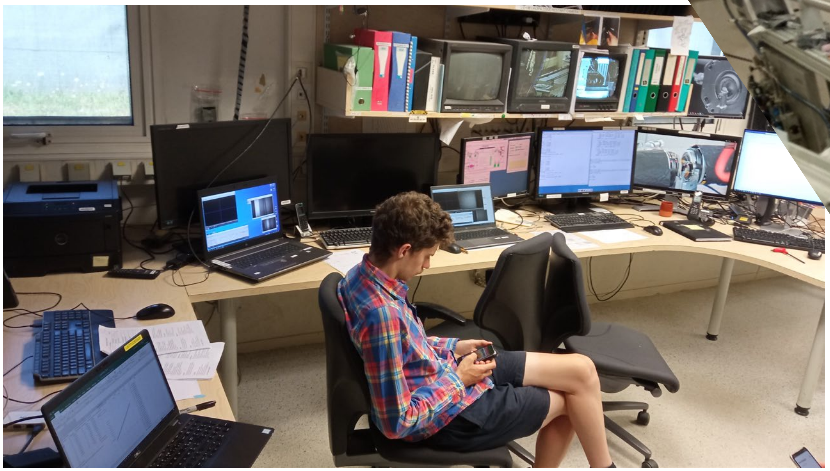
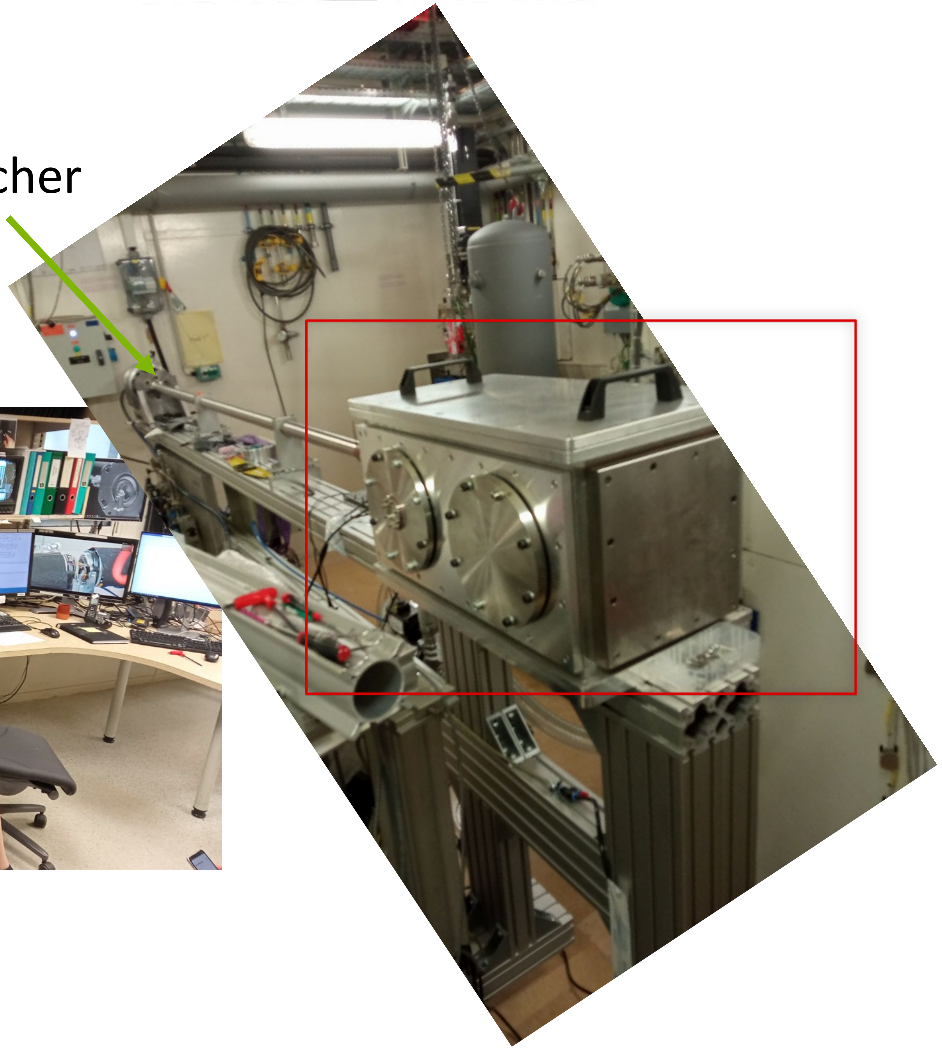
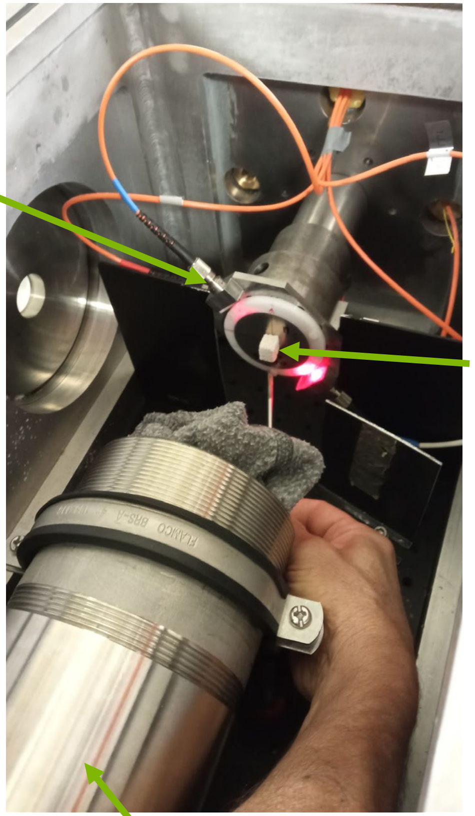


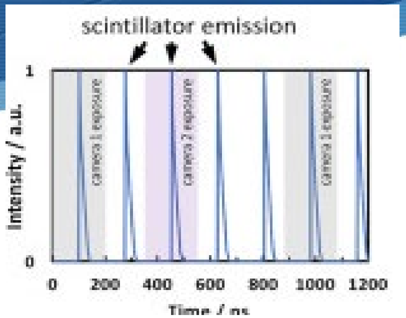
Plate impact at ESRF







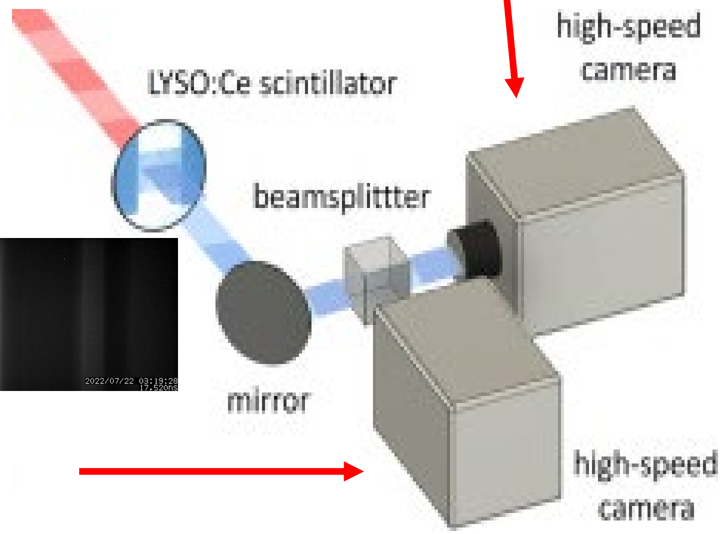
X-Ray Scintillator

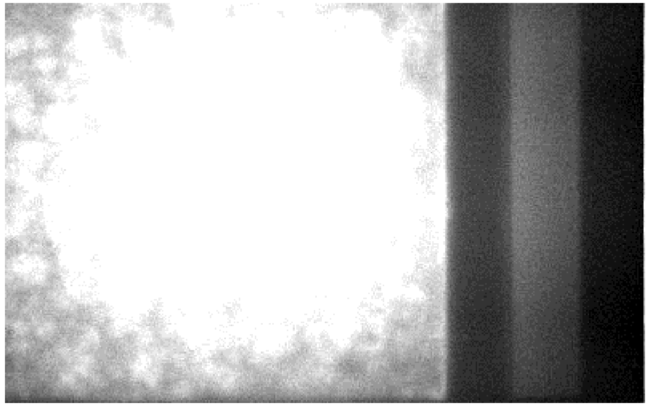


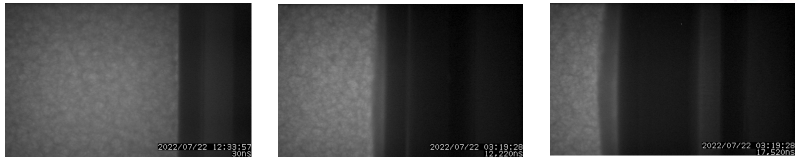
- X-Ray bursts every 176ns (pulse duration 100-120ps)
- Convert X-Rays to visible light for cameras
- Greyscale images (16 bits)
- Cameras frequency ≈ 2 MHz

Record scintillator light

X-Rays



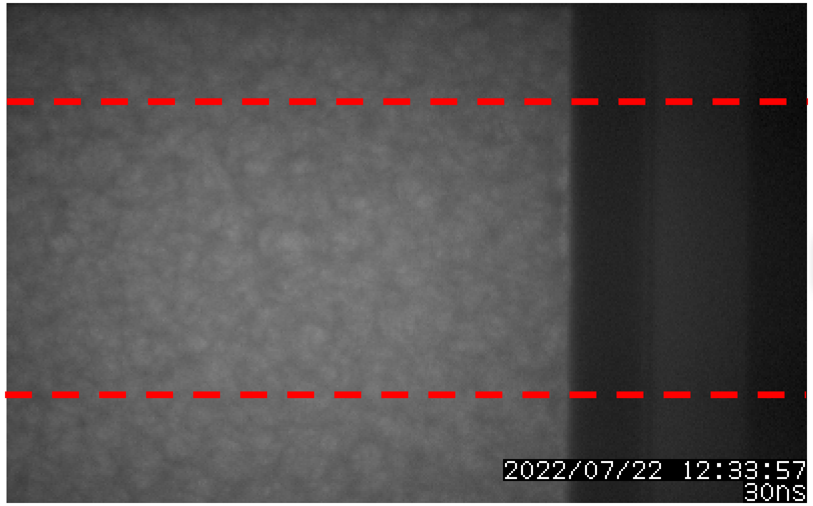




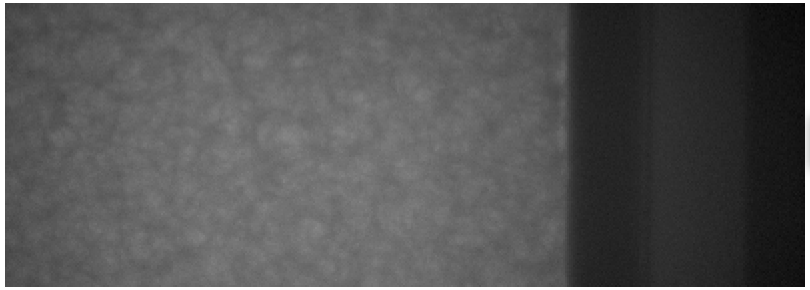
Record sample compaction

X-Rays visualisation at ESRF, picture from [Farbaniec, 2021]

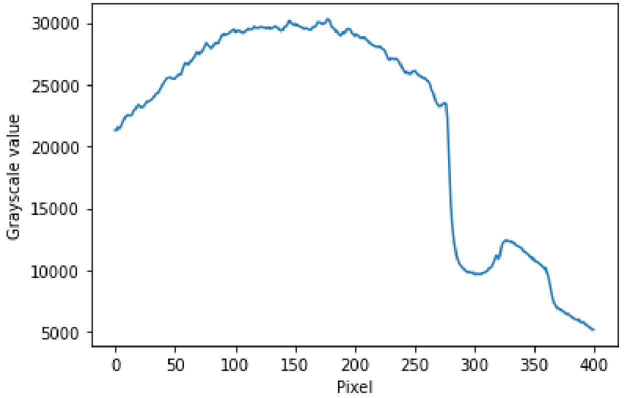
Sample images treatment



Greyscale Image



Top and bottom deletion



Average on column

-> 1D image

N greyscale profiles vs pixel position

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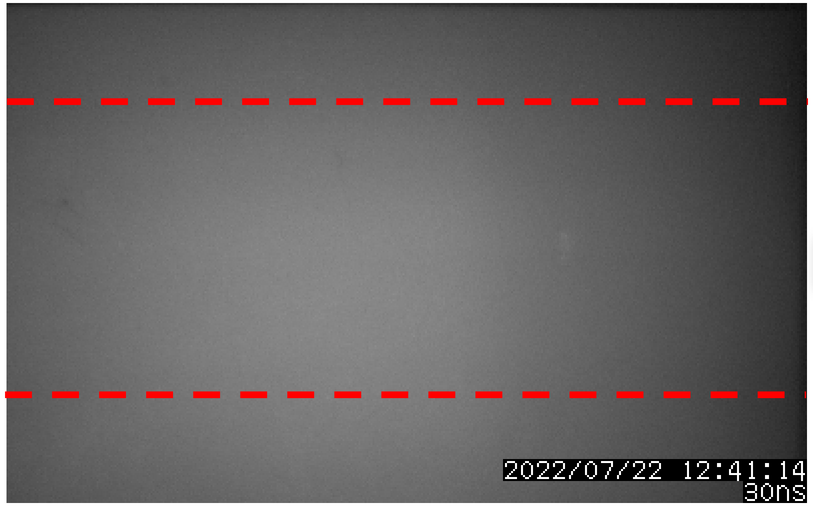
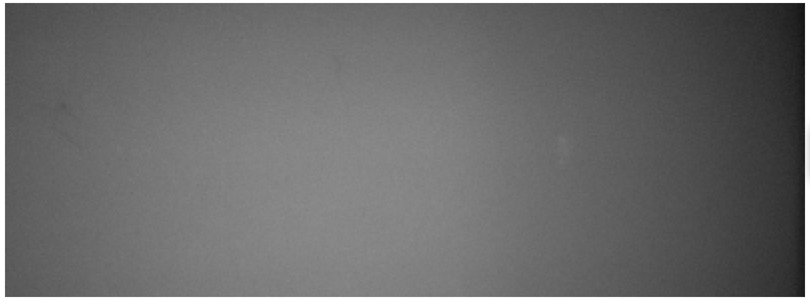
Scintillator images treatment

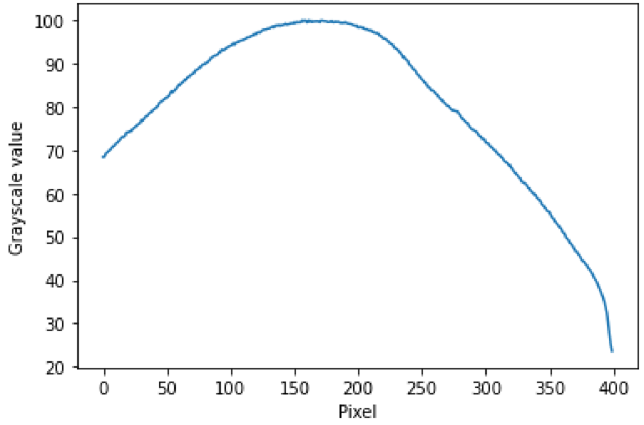


Greyscale Background

Image



Top and bottom deletion

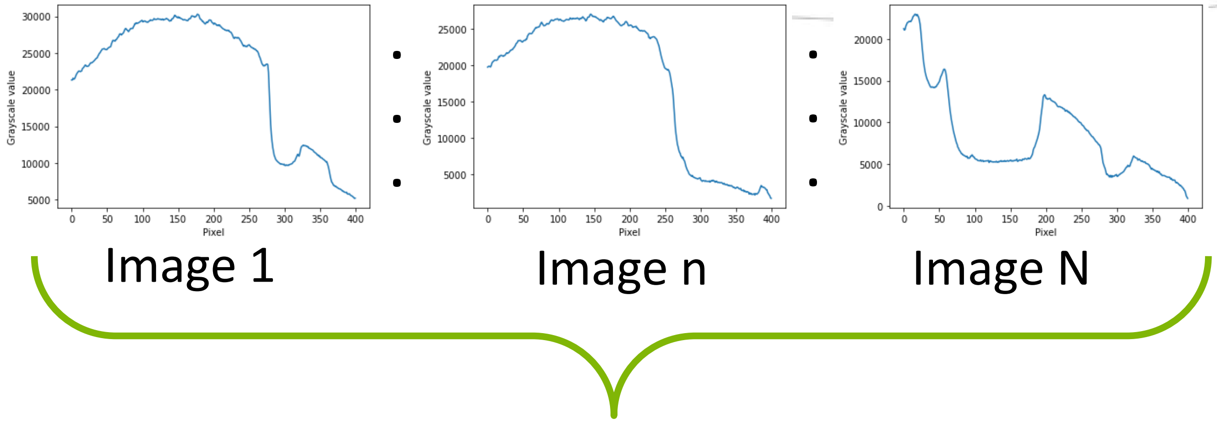


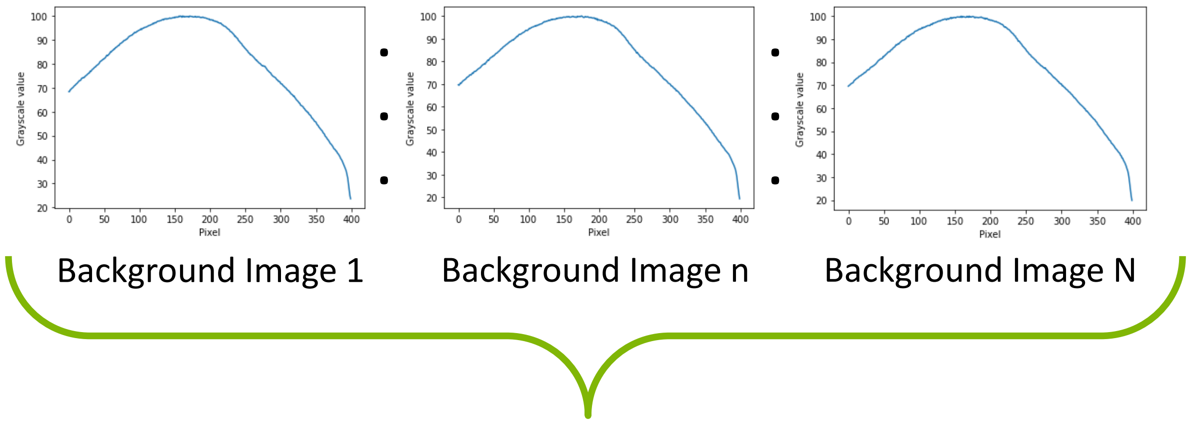
Average on column

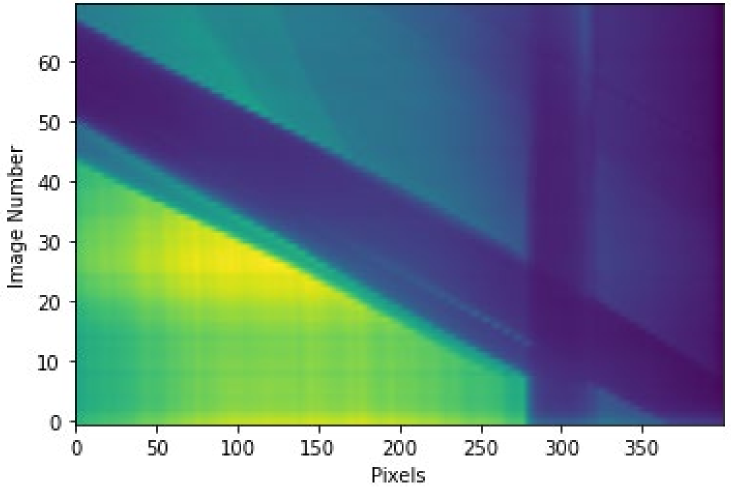
-> 1D image

N greyscale profiles vs pixel position

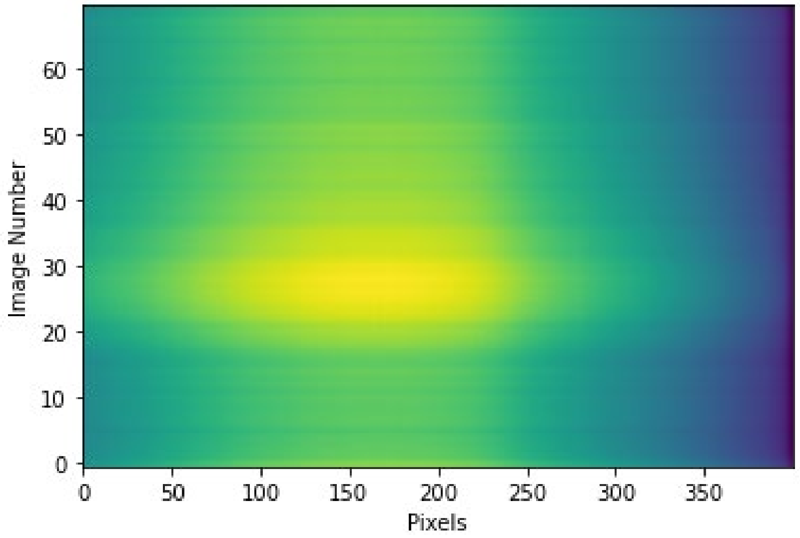
Image compilation





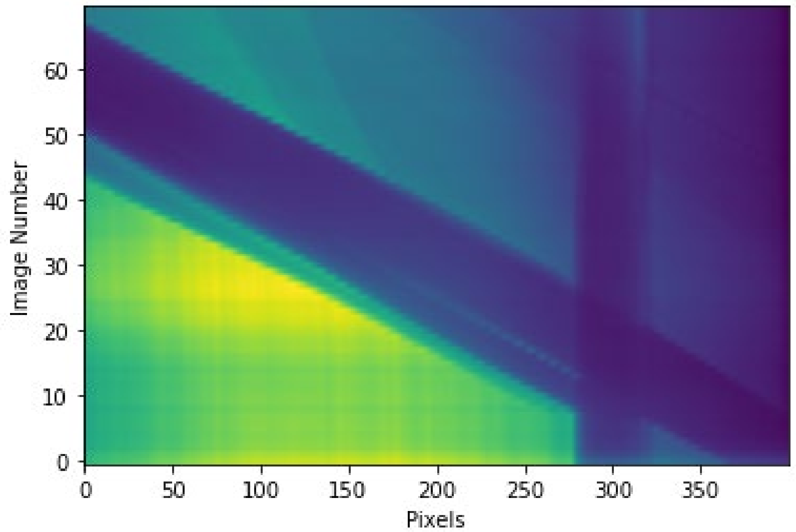


Shot image compilation

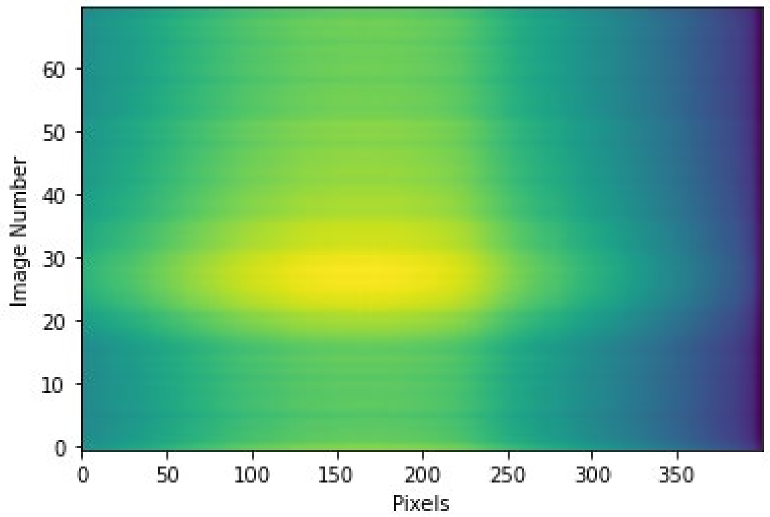


Background image compilation

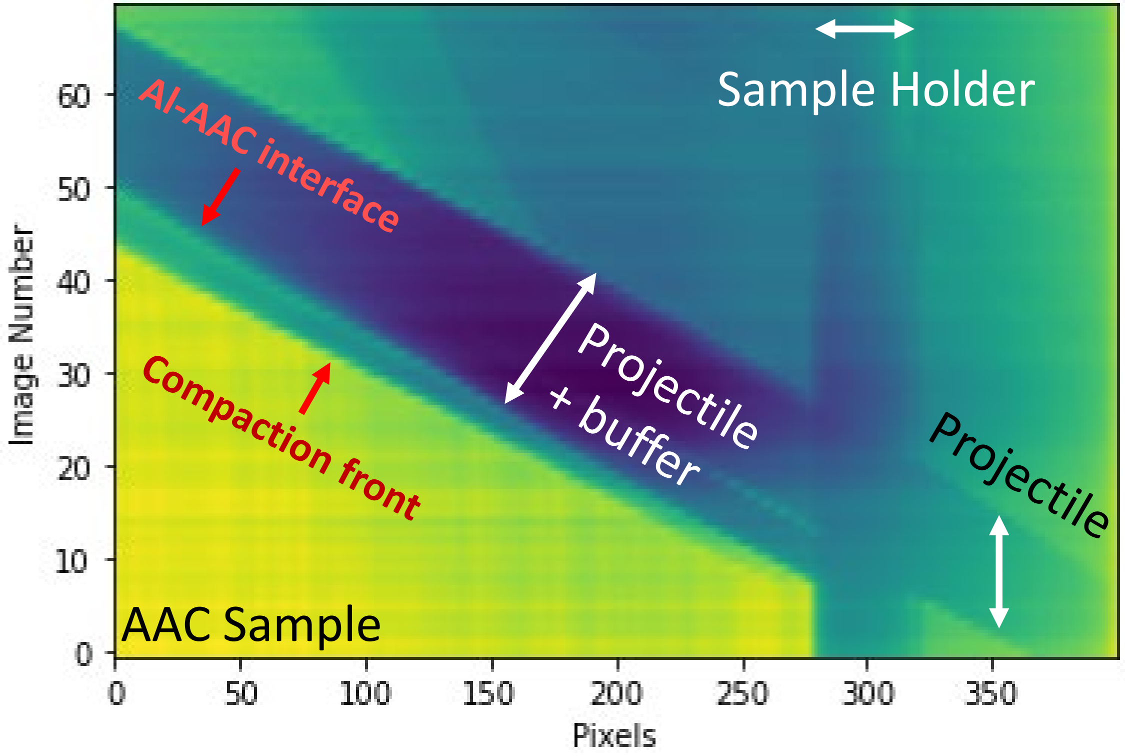
Flat-field correction



Shot image compilation

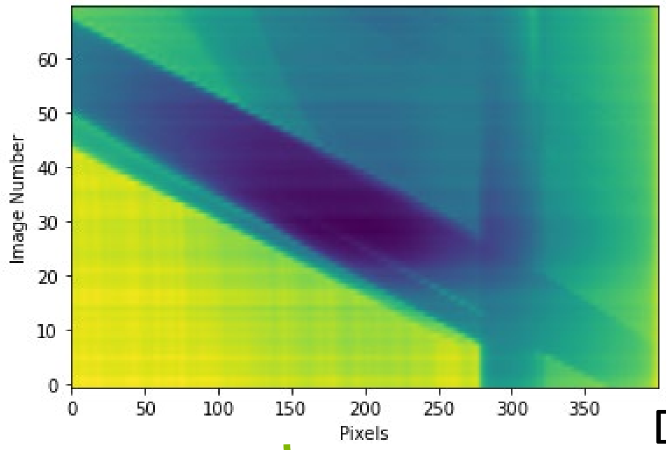


Background image compilation

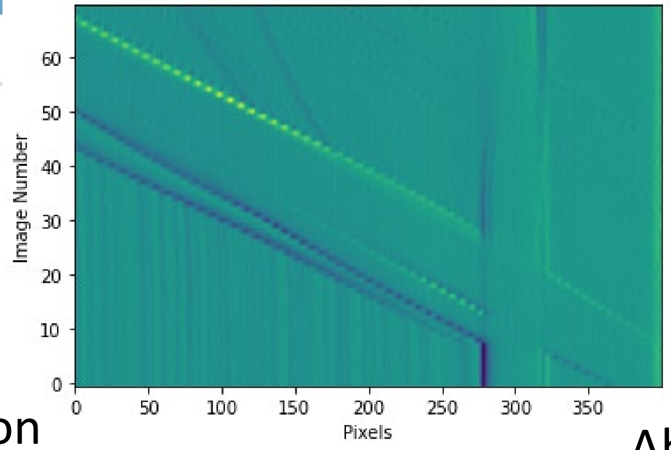


Shot image compilation after flat-field correction

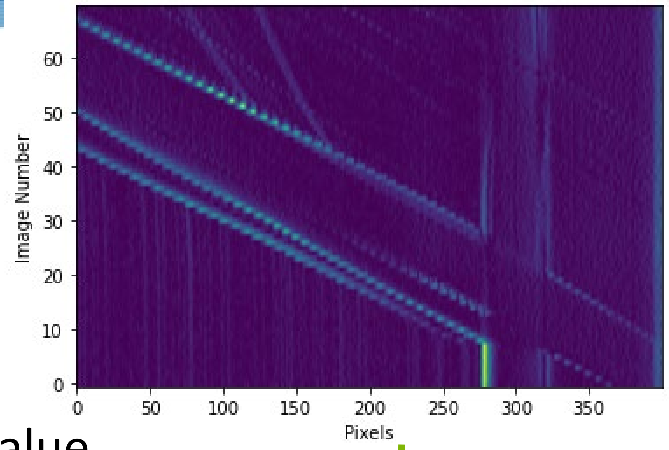
Space-time diagram creation



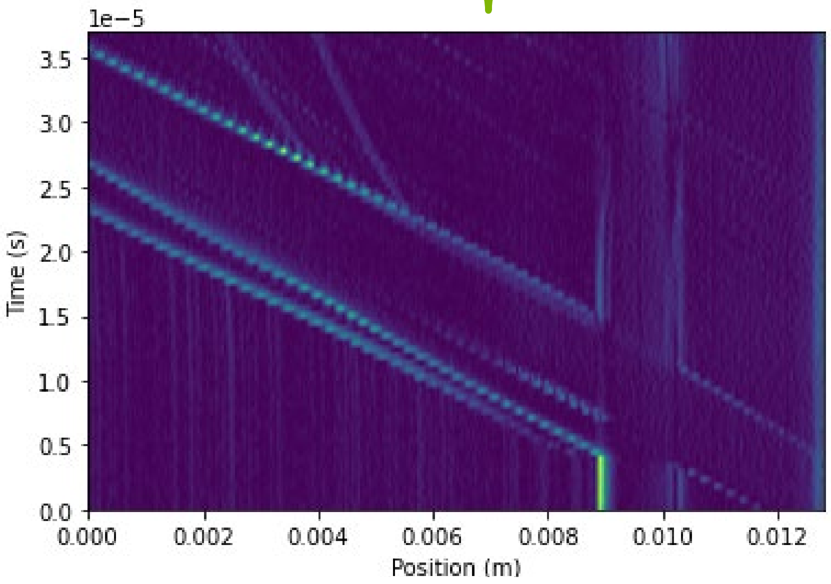
Derivation



Absolute value

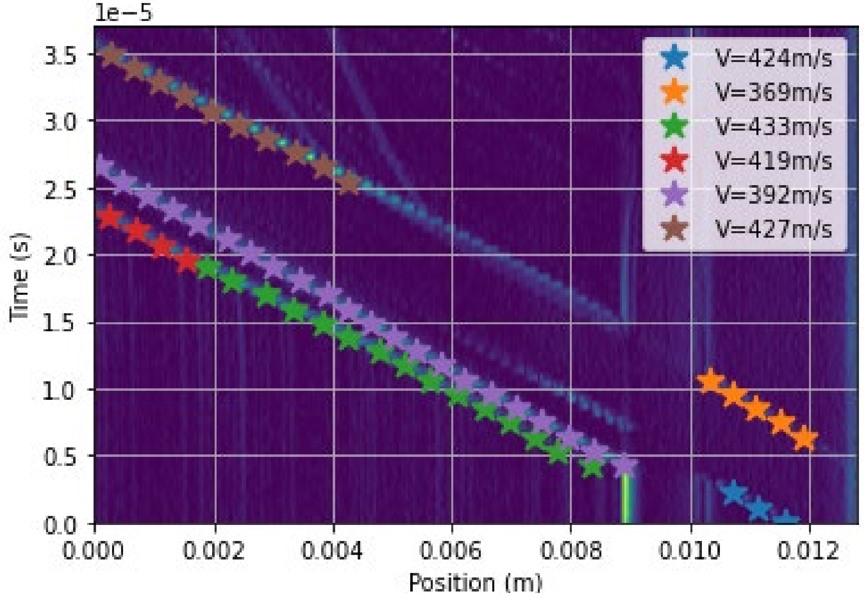


Time and space scales



X-t (Space-time) diagram

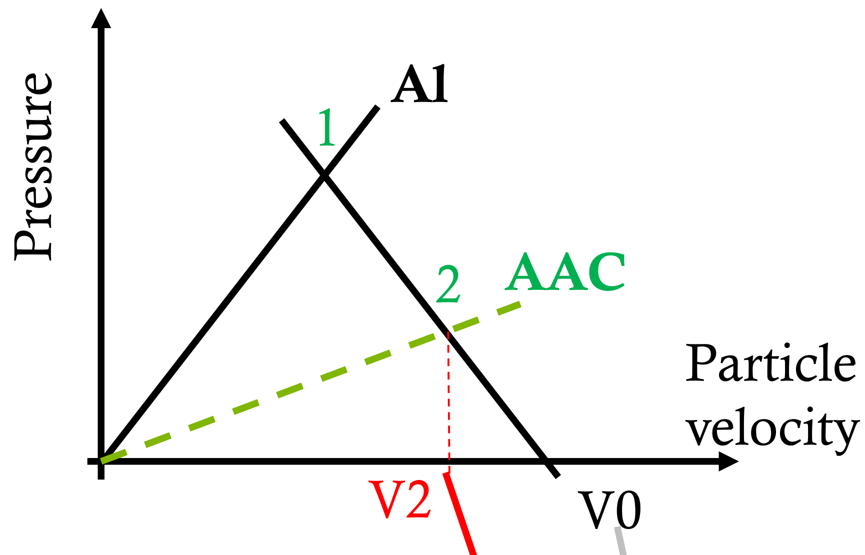
Curve tracking and fitting



X-t (Space-time) diagram

Shock polar analysis

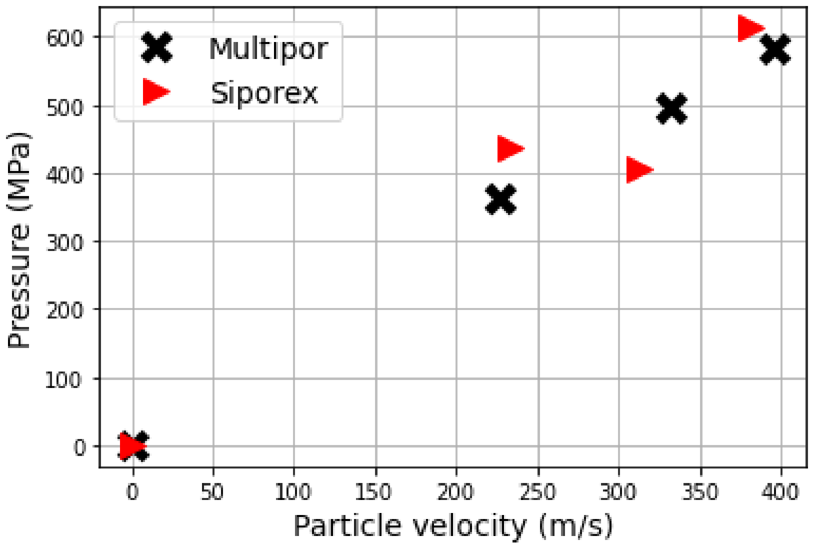
- 1D plane shock approach
- Known Aluminium properties, unknown AAC properties
- 3 velocities for each AAC : 3 points on AAC shock polar



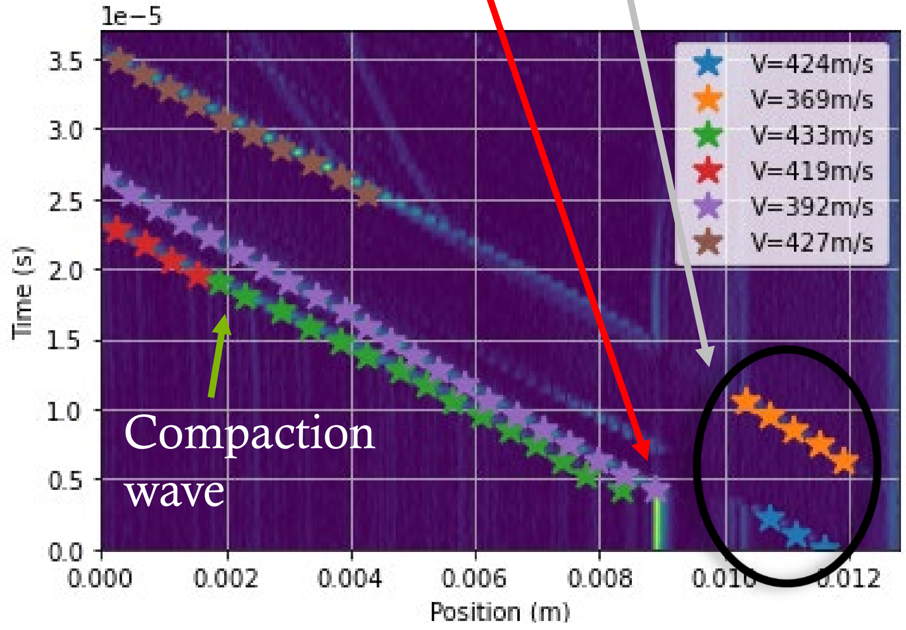
P-u (Pressure particle velocity) diagram

What to fit ?
Porous approach ?

More points required



P-u diagram with computed data from plate-impact experiment for Multipor and Siporex

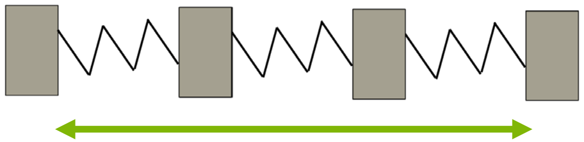


X-t (Space-time) diagram

AAC compaction description by simplified approach

- AAC sample ≈ N [mass AAC;spring;mass] system with

N=$\frac{median\ cell\ size}{sample\ thickness}$

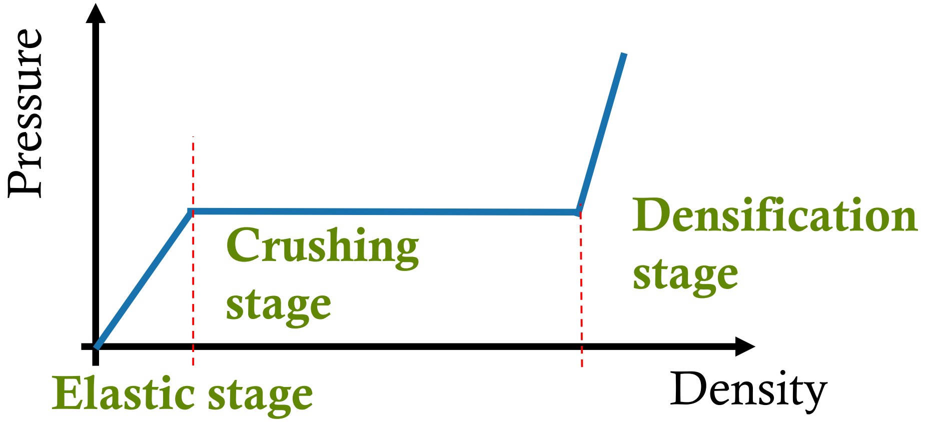


- So called « AAC spring »:
  - If elastic stage : $F = -k.x$
  - If crushing stage : $F = -RM.A$
  - If densification stage : rigid body

With : A the sample section,
$k = A.\frac{E}{L}$ and L the cell length

N cells of size

Multipor median cell size = 0,7mm
Siporex median cell size = 1 mm



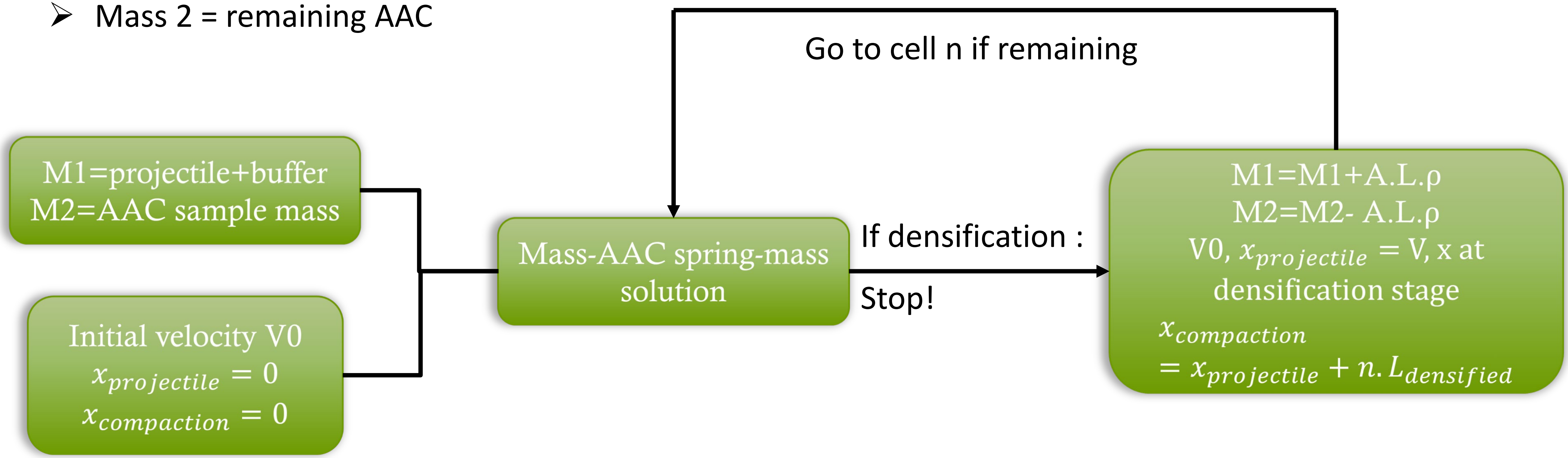
Porous P-α model for porous materials [Aminou, CFM 2022]

AAC compaction, simplified approach

- Iterative approach to track compaction front :
  - 1 mass-AAC spring-mass system at a time
  - Mass 1 = projectile+buffer+densified AAC
  - Mass 2 = remaining AAC

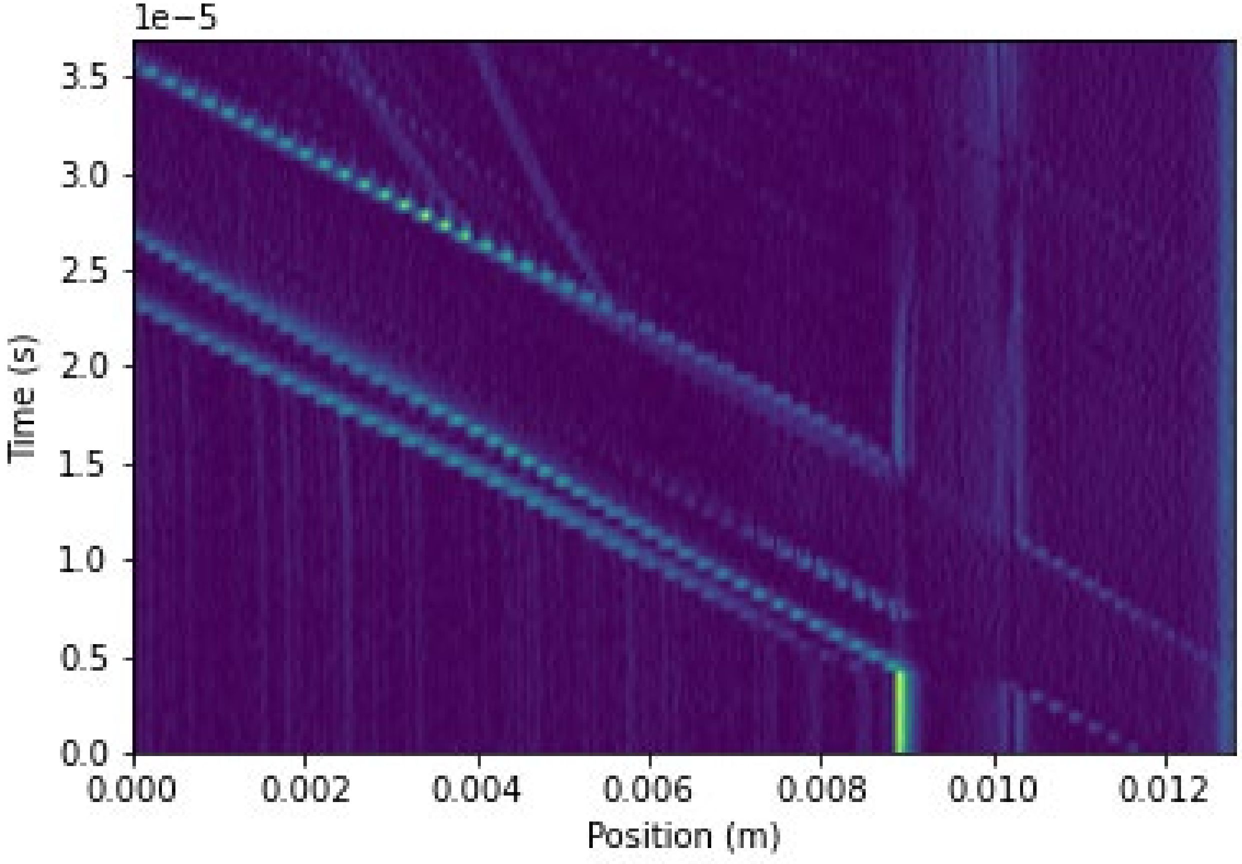
$$L_{densified} = \frac{m_{cell}}{\rho_{densified} . L^2}$$

$$m_{cell} = m_{sample} . \frac{L^3}{A . L_{sample}}$$



Model results for Multipor

- Multipor samples impacted at 250 m/s, 335 m/s and 400 m/s
- Correct agreement between model and experiment
- Same result for all impact velocity



X-t diagramm for 400m/s shot on Multipor

Model results for Multipor

- Multipor samples impacted at 250 m/s, 335 m/s and 400 m/s
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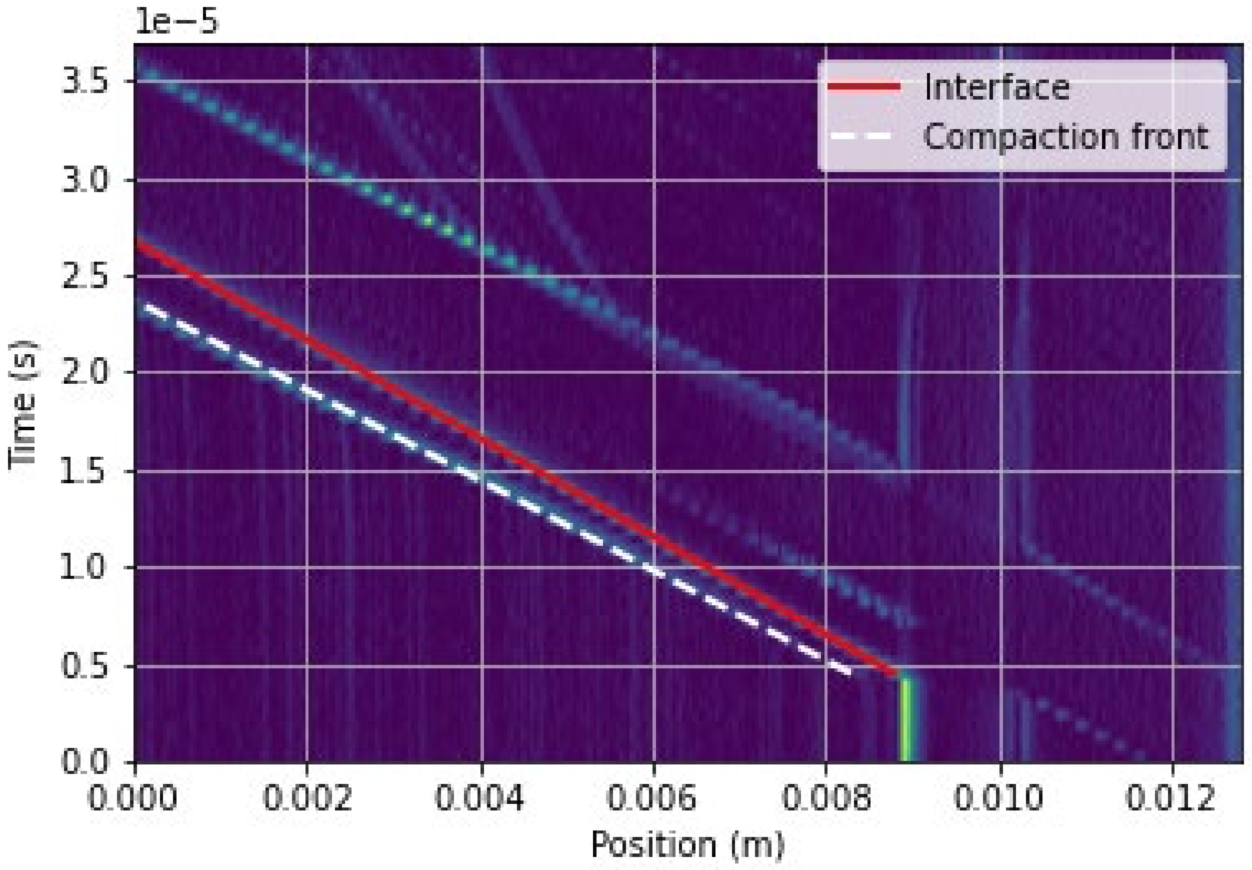
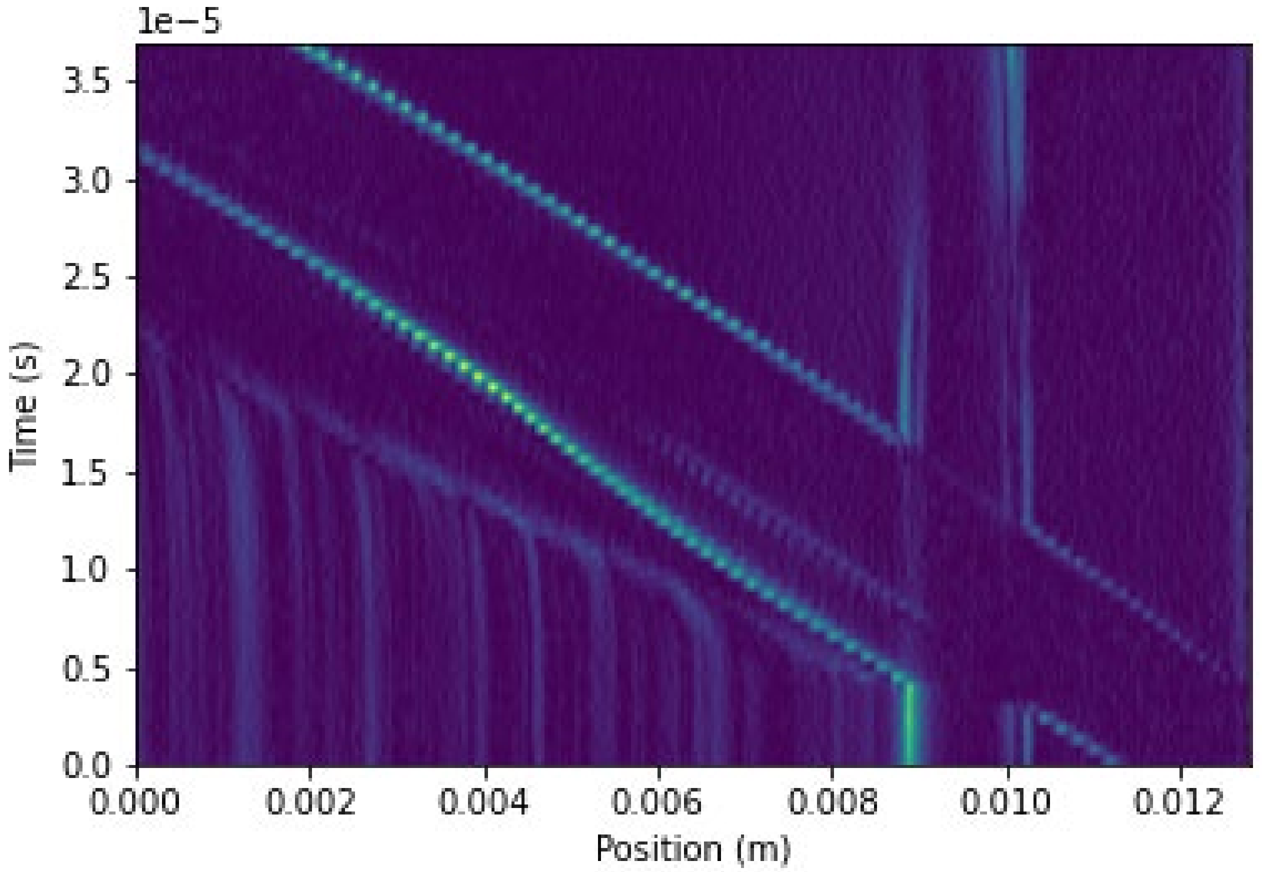


X-t diagramm for 400m/s shot on Multipor superimposed with mass-AAC spring-mass model

Model results for Siporex

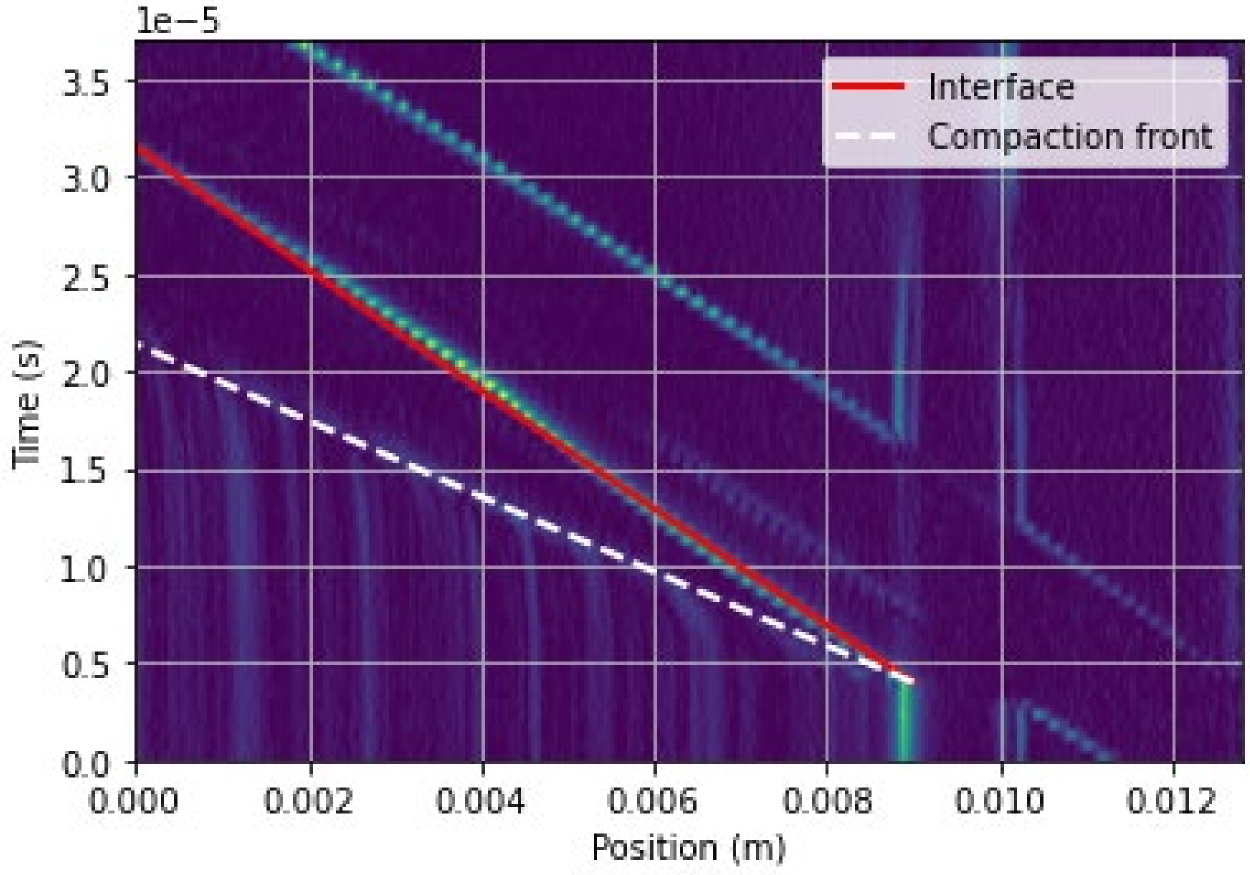
- Multipor samples impacted at 250 m/s, 335 m/s and 400 m/s
- Correct agreement between model and experiment
- Same result for all impact velocity



X-t diagramm for 335m/s shot on Siporex

Model results for Siporex

- Multipor samples impacted at 250 m/s, 335 m/s and 400 m/s
- Correct agreement between model and experiment
- Same result for all impact velocity

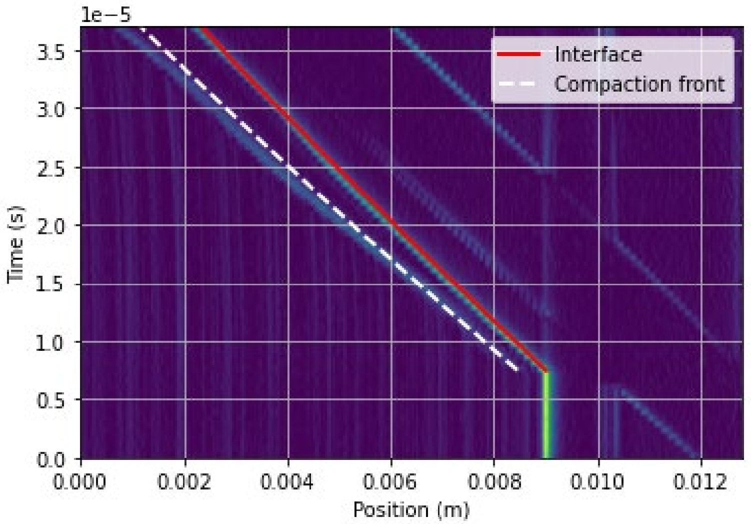


Result for 335m/s shot on Siporex superimposed with mass-AAC spring-mass model

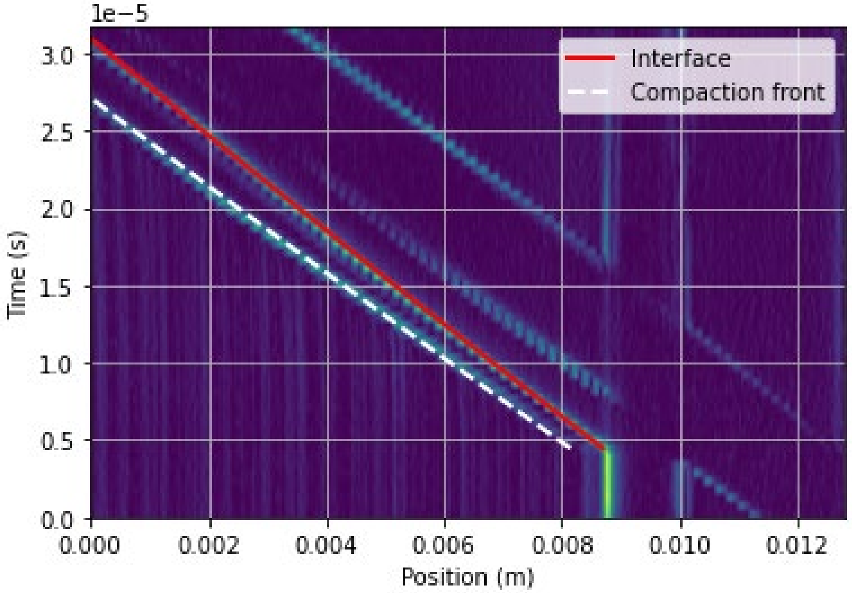
Results for Multipor impacted at 250m/s, 335m/s, 400m/s

- Multipor samples impacted at 250 m/s, 335 m/s and 400 m/s

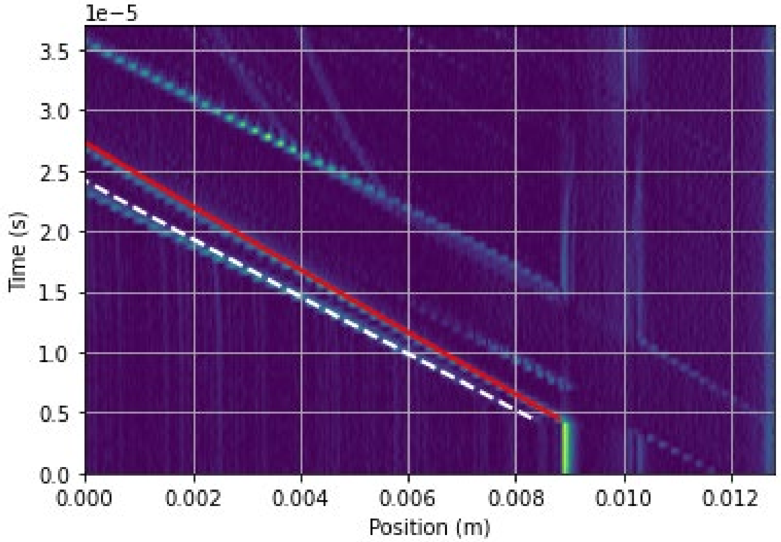
- Correct agreement between model and experiment



Result for 250m/s shot on Multipor superimposed with mass-AAC spring-mass model



Result for 335m/s shot on Multipor superimposed with mass-AAC spring-mass model

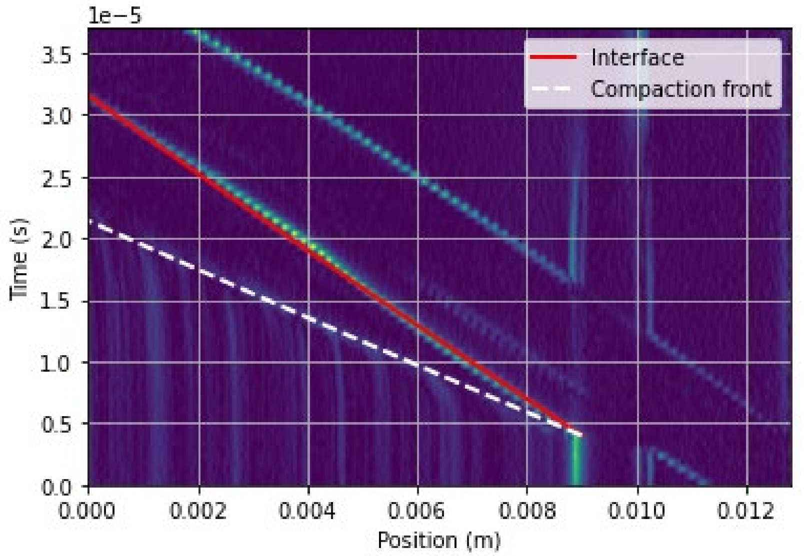


Result for 400m/s shot on Multipor superimposed with mass-AAC spring-mass model

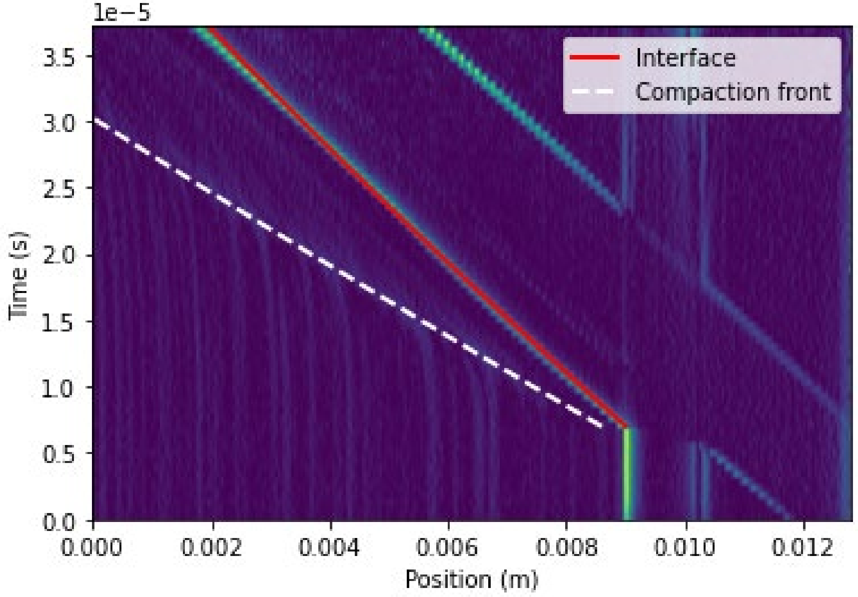
Results for Siporex impacted at 250m/s, 335m/s, 400m/s

- Siporex samples impacted at 250 m/s, 335 m/s and 400 m/s

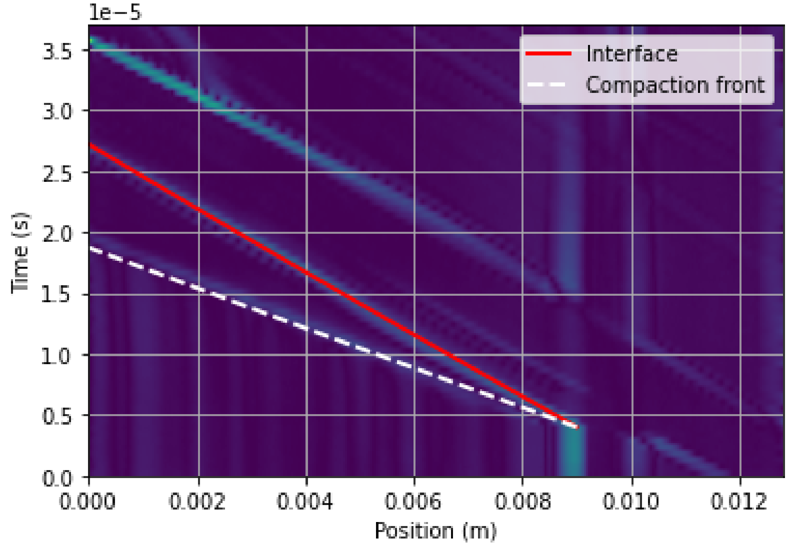
- Correct agreement between model and experiment



Result for 250m/s shot on Multipor superimposed with mass-AAC spring-mass model



Result for 335m/s shot on Siporex superimposed with mass-AAC spring-mass model



Result for 400m/s shot on Siporex superimposed with mass-AAC spring-mass model

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Conclusions

- 3 points of the Hugoniot could be plotted for 2 AAC
- Compaction observed at fast xray for two AAC (Multipor and Siporex)
- Tool development by x-t analysis to follow the compaction process
- Proposition of an analytical model for compaction description
- Correlation between analytical results and experimental ones

- More experiments required at slower and higher velocities
- Numerical simulation could correlate ?