The Development of Fluidised Powder Target Technology for a Neutrino Factory or Muon Collider

Ottone Caretta, Chris Densham, Peter Loveridge

Rutherford Appleton Laboratory

22 September 2010

High Power Targets

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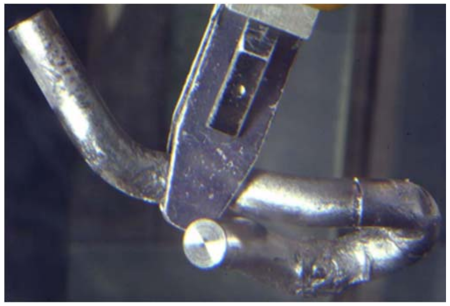
Looking for the 'Goldilocks' target technology

SOLIDS

- Monolithic
- Segmented
- Pebble bed
- Moving

LIQUIDS

- Contained liquids
- Open jets



Too bendy?

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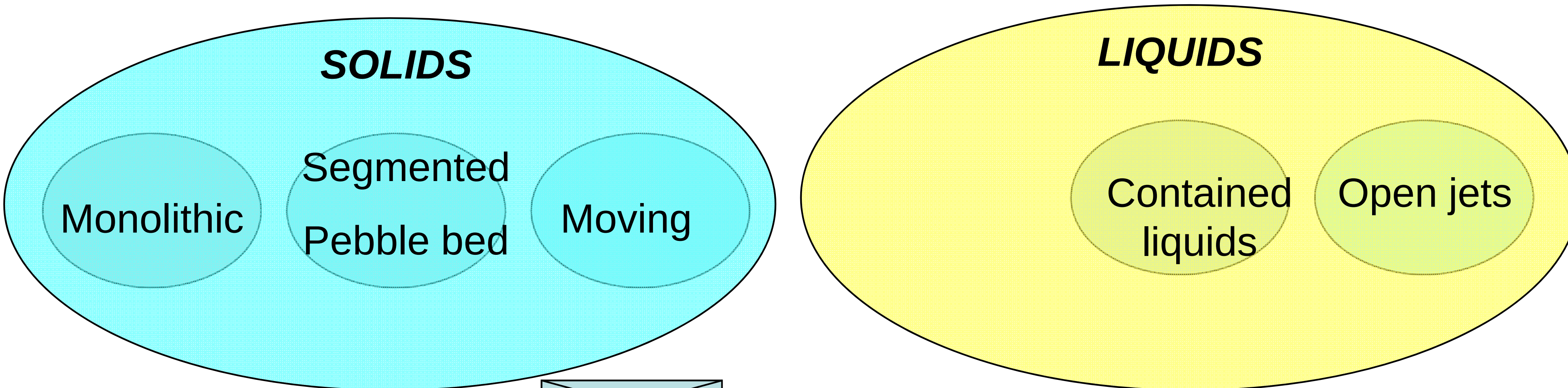

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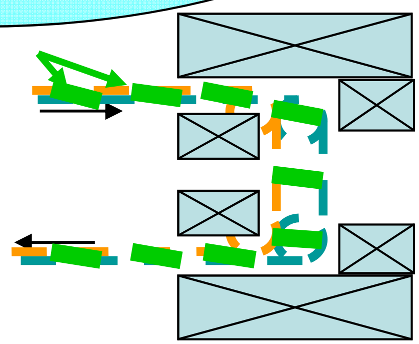

Too complicated?

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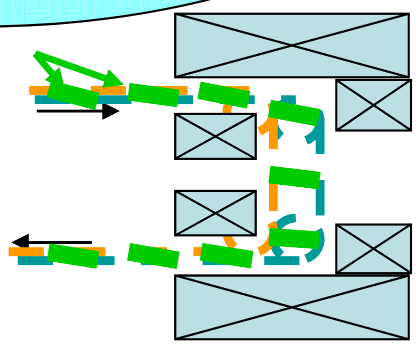

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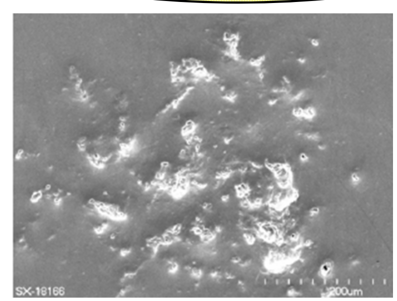

Too cavitated?

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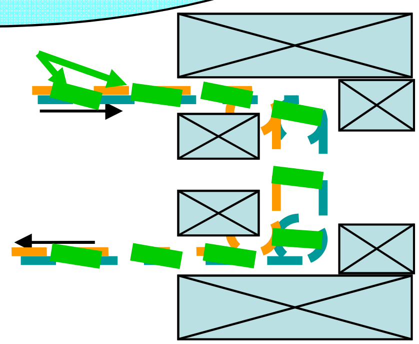

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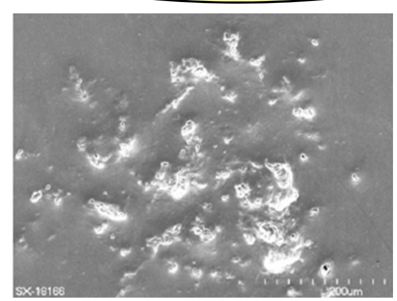

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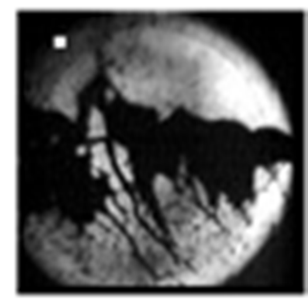

Too messy?

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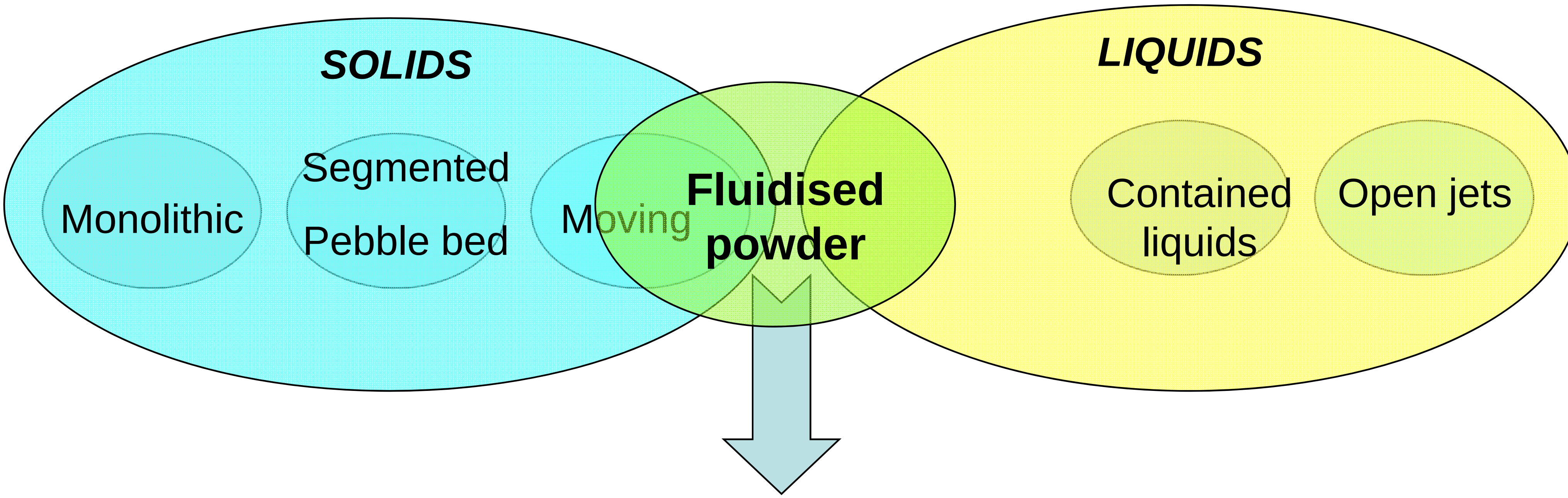

Not too solid and
not too liquid:
Just Right?

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Fluidised powder target propaganda

- **Shock waves**
  - Material is already broken – intrinsically damage proof
  - No cavitation, splashing or jets as for liquids
  - high power densities can be absorbed without material damage
  - Shock waves constrained within material grains, c.f. sand bags used to absorb impact of bullets
- **Heat transfer**
  - High heat transfer both within bulk material and with pipe walls - so the bed can dissipate high energy densities, high total power, and multiple beam pulses
- **Quasi-liquid**
  - Target material continually reformed
  - Can be pumped away, cooled externally & re-circulated
  - Material easily replenished
- **Other**
  - Can exclude moving parts from beam interaction area
  - Low eddy currents i.e. low interaction with NF solenoid field
  - Fluidised beds/jets are a mature technology
  - **Most issues of concern can be tested off-line -> experimental programme**

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Questions for the experimental programme

- Can a dense material such as tungsten powder be made to flow?
- Is tungsten powder fluidisable (it is much heavier than any material studied in the literature)?
- Is it possible to generate a useful fluidised powder geometry?
- Is it possible to convey it
  - in the dense phase?
  - in the lean phase?
  - In a stable mode?
- What solid fraction is it possible to achieve?
  (a typical loading fraction of 90% w/w solid to air ratio is not good enough!)
- How does a dense powder jet behave?

- **Difficult to model bulk powder behaviour analytically**
- **Physical test programme underway:**
  - **First results *March 2009***

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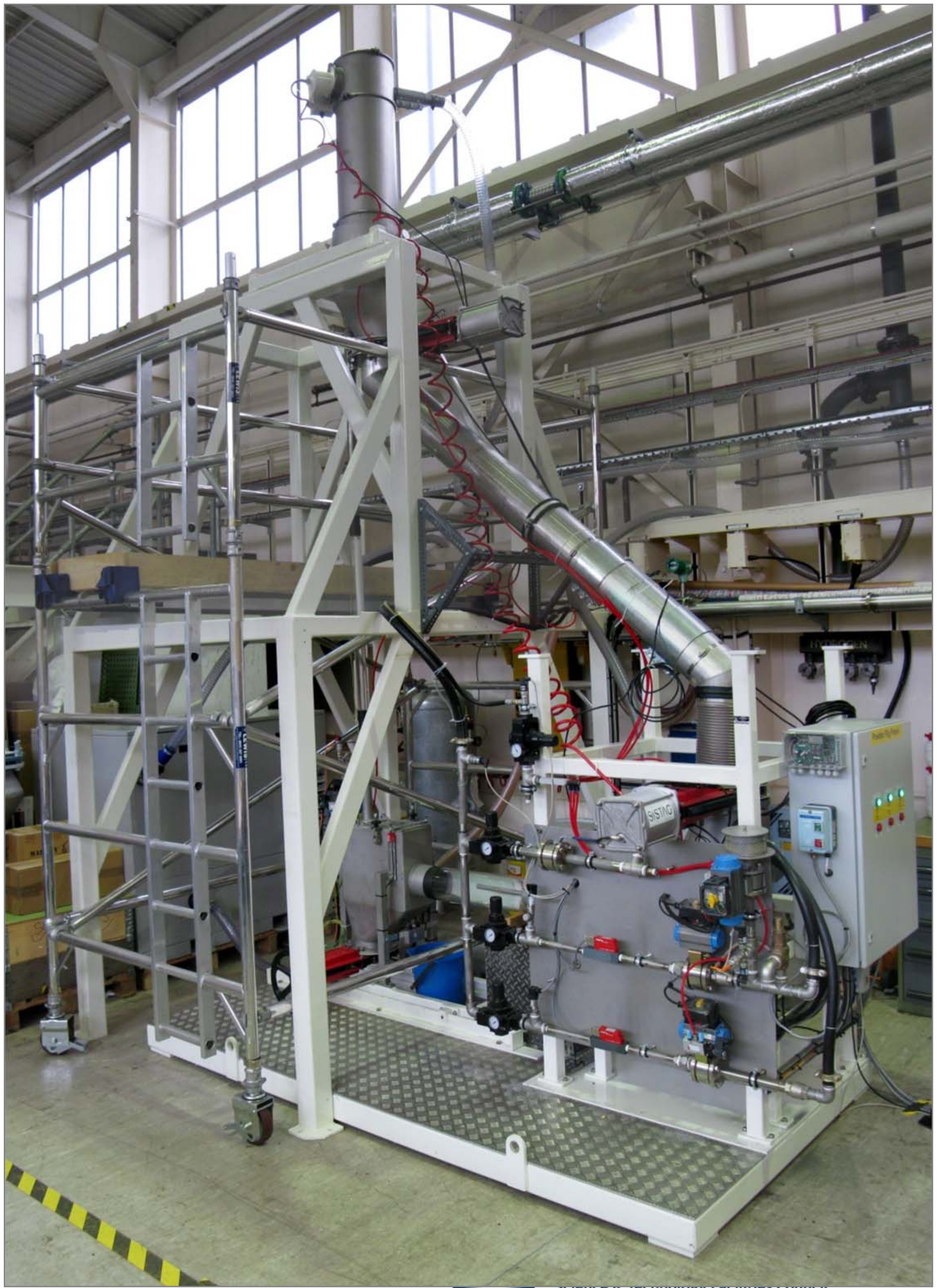
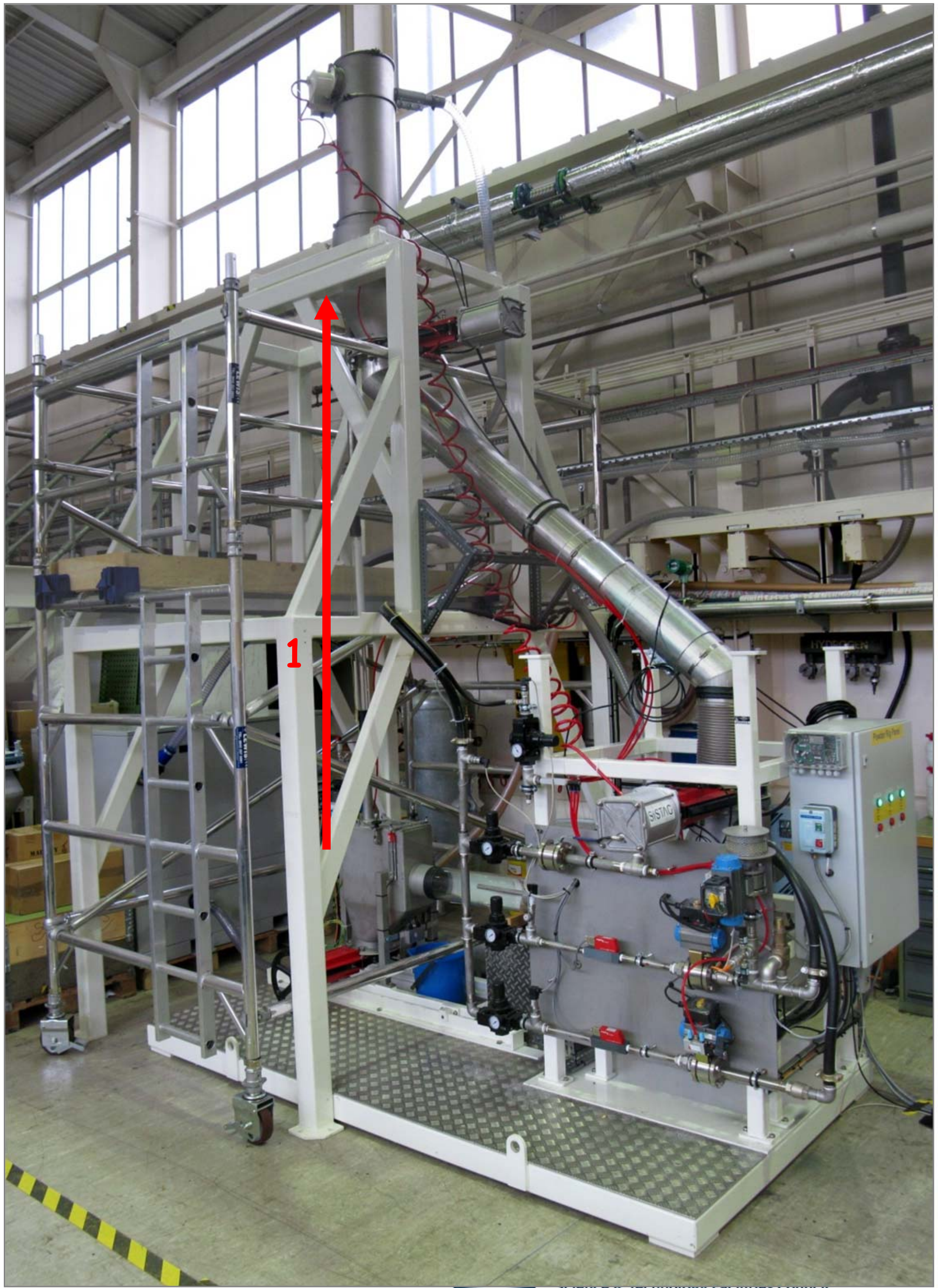
Test rig at RAL

- Powder
  - Rig contains 100 kg Tungsten
  - Particle size < 250 microns
- Total ~10,000 kg powder conveyed so far
  - > 100 ejection cycles
  - Equivalent to 20 mins continuous operation
- Batch mode
  - Tests individual handling processes before moving to a continuous flow loop



Summary of Operation

1. Suction / Lift



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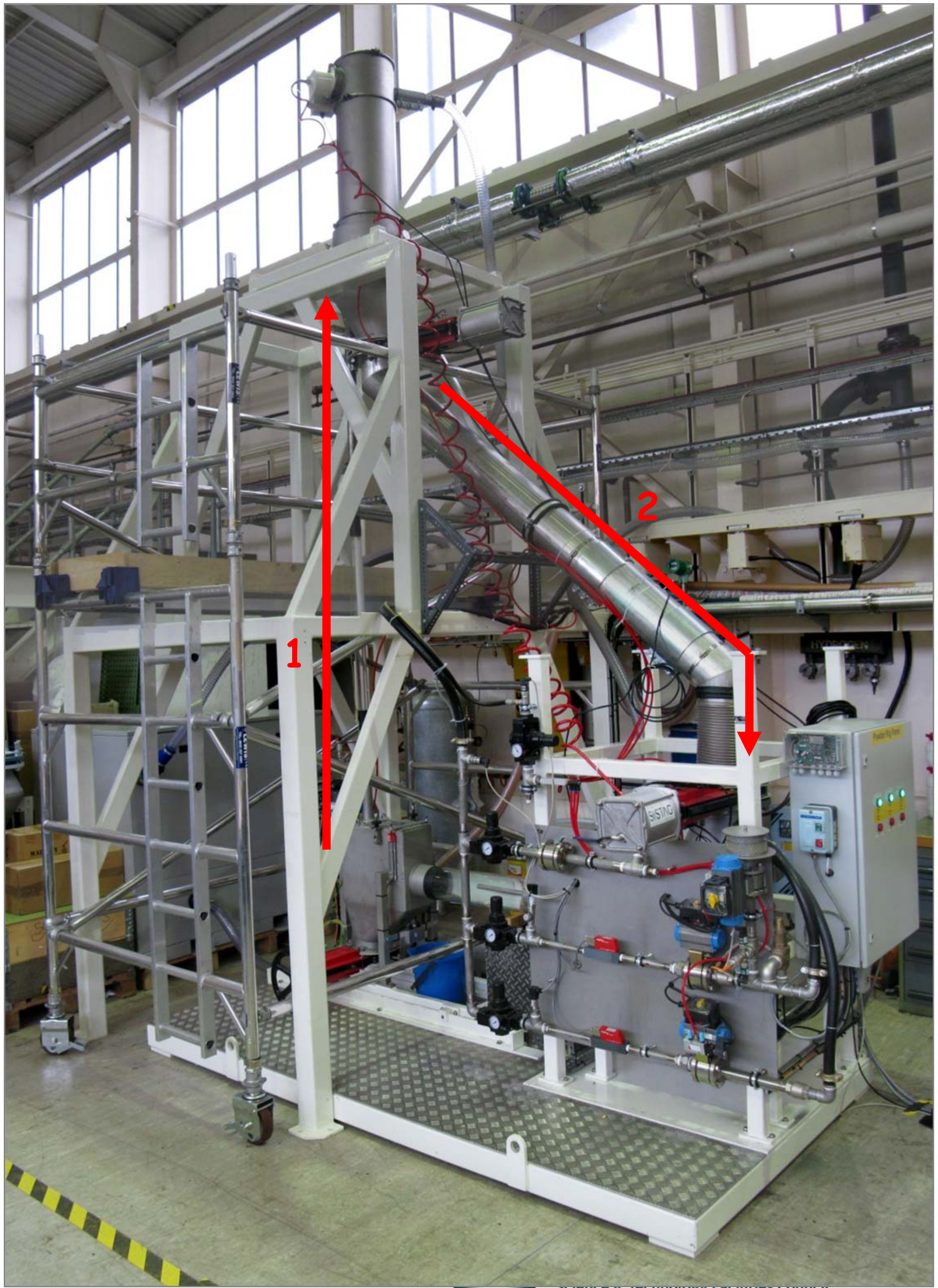
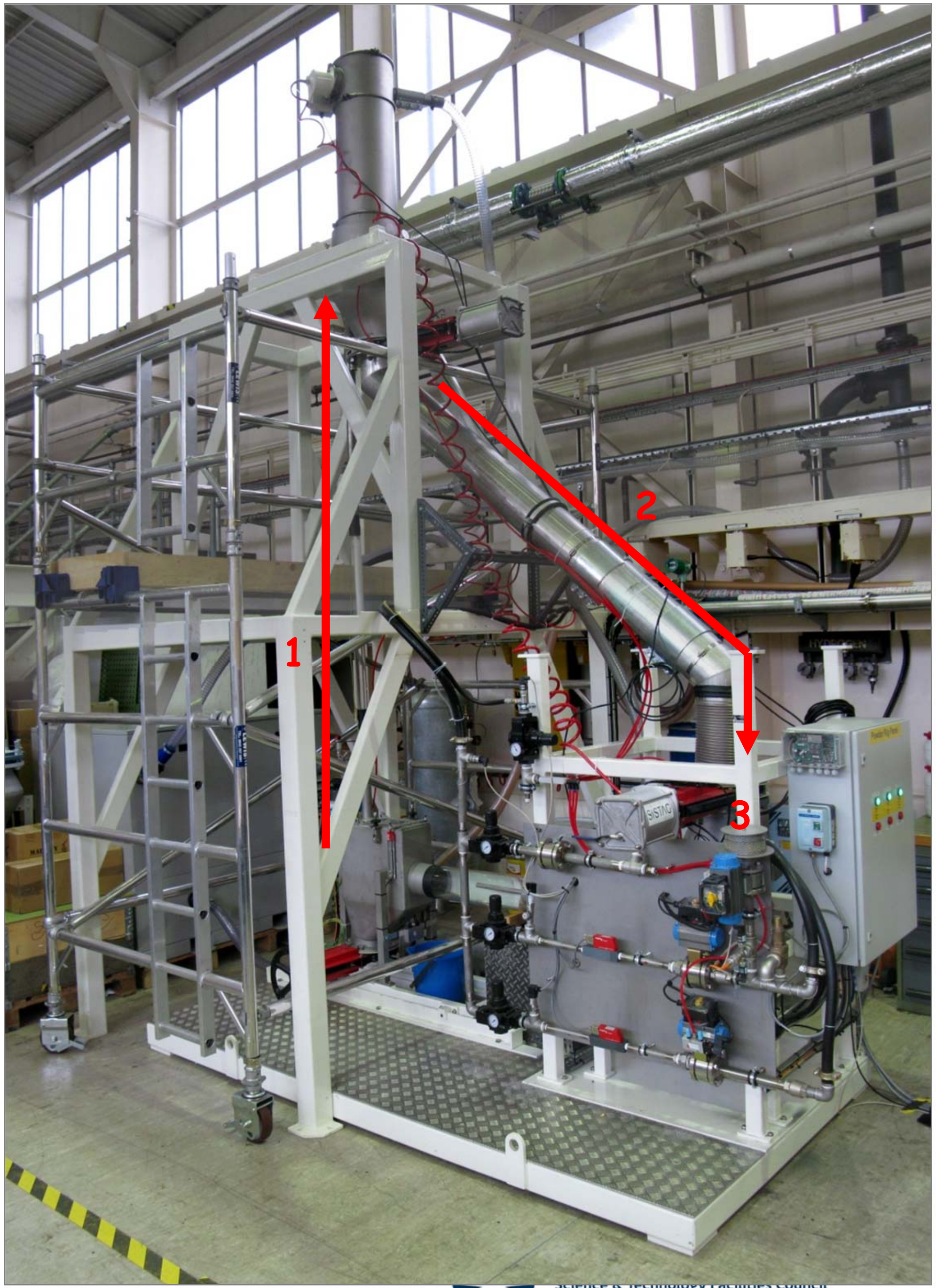
Summary of Operation

1. ***Suction / Lift***
2. ***Load Hopper***



Summary of Operation

1. *Suction / Lift*
2. *Load Hopper*
3. *Pressurise Hopper*



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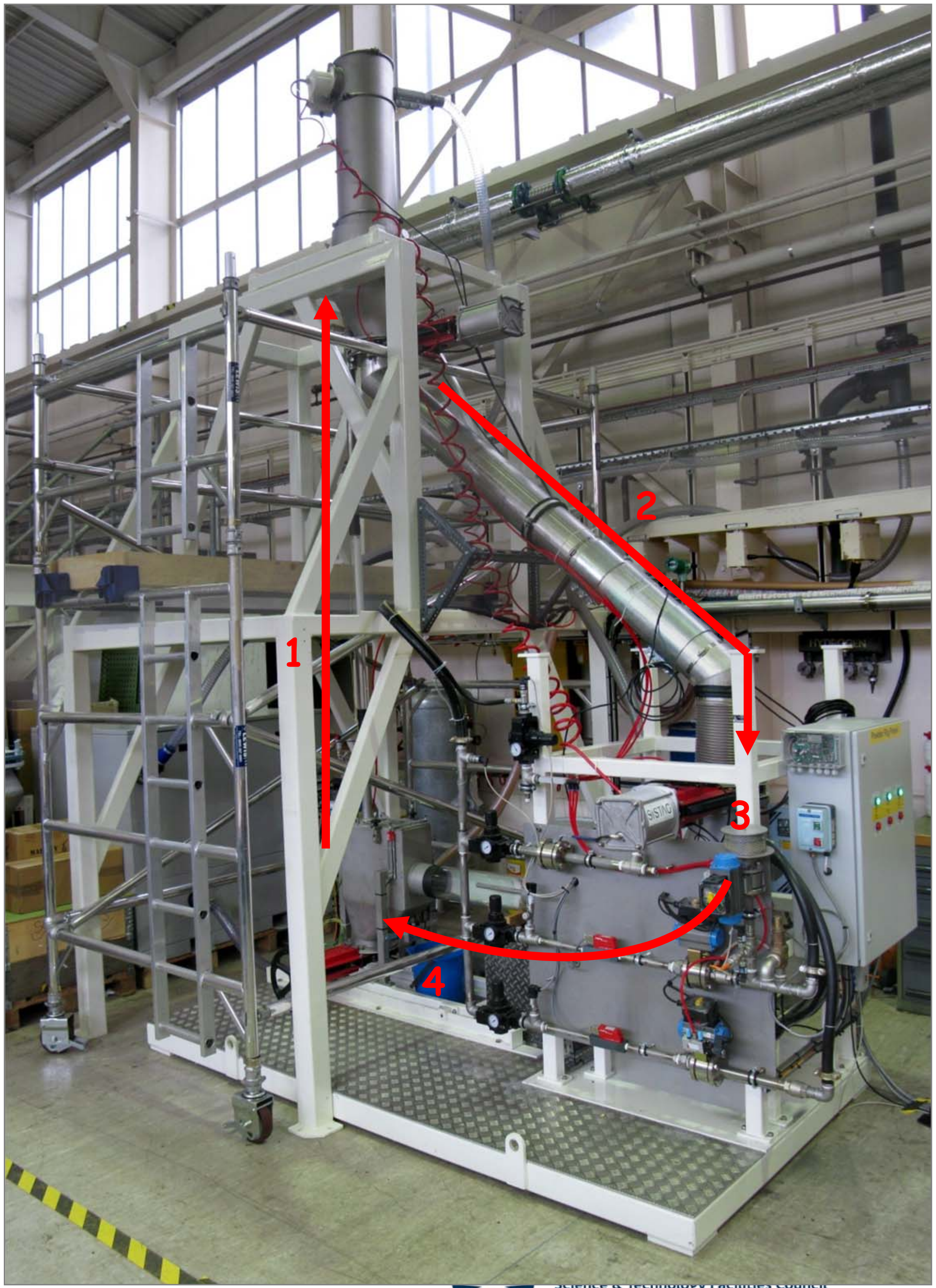
Summary of Operation

1. ***Suction / Lift***
2. ***Load Hopper***
3. ***Pressurise Hopper***
4. ***Powder Ejection and Observation***



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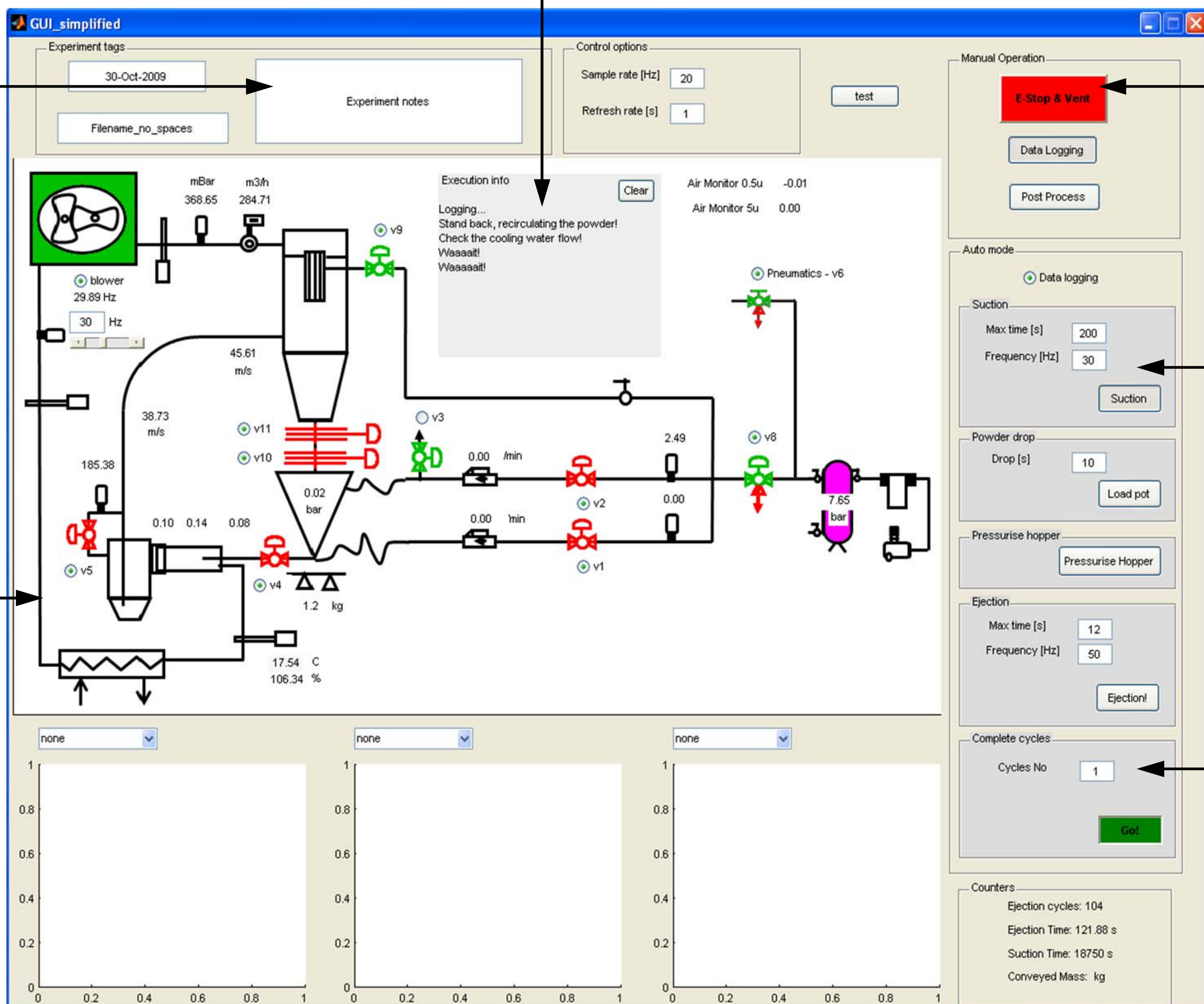
Control Interface (GUI)

- Fully automated control system
  - Process control
  - Data Logging @ 20 Hz
  - Hard-wired safety interlocks



Control System Interface (MATLAB)

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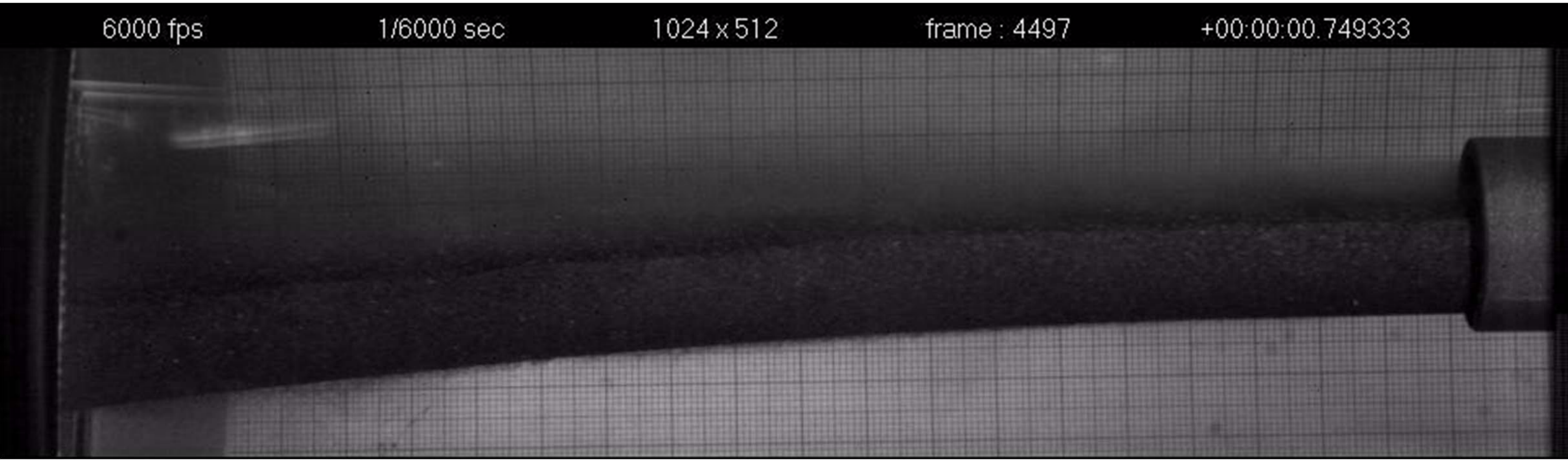
Le jet d'W



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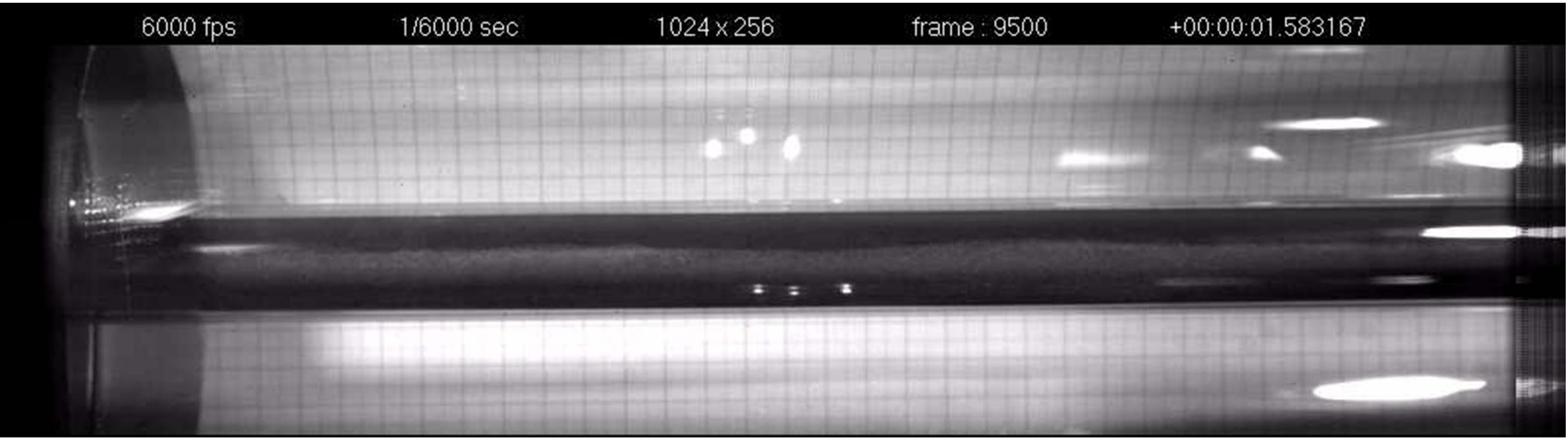
Contained stable flow



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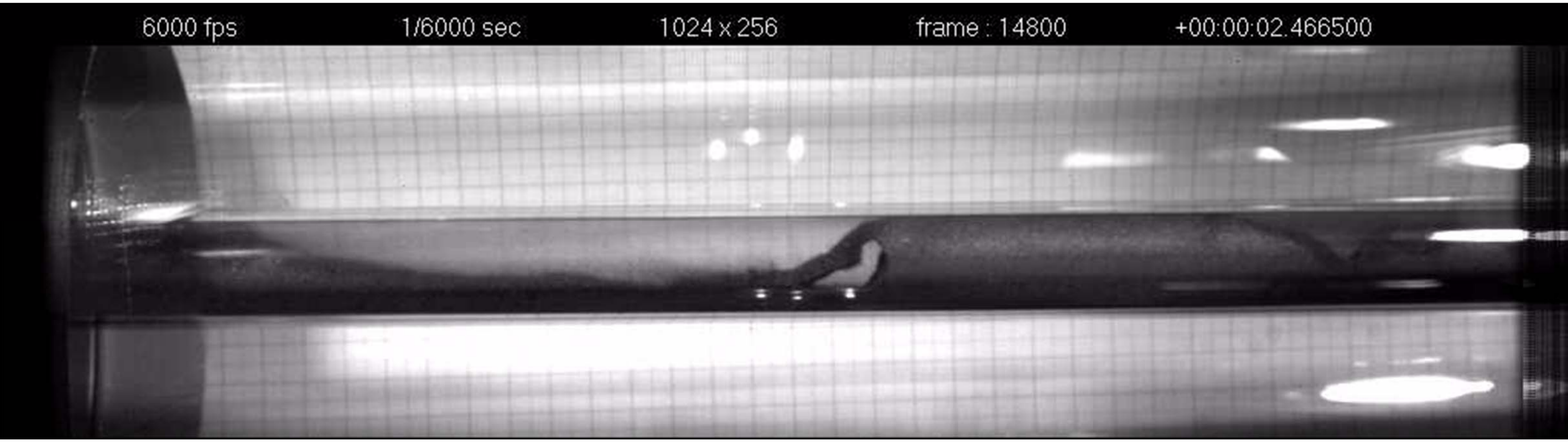
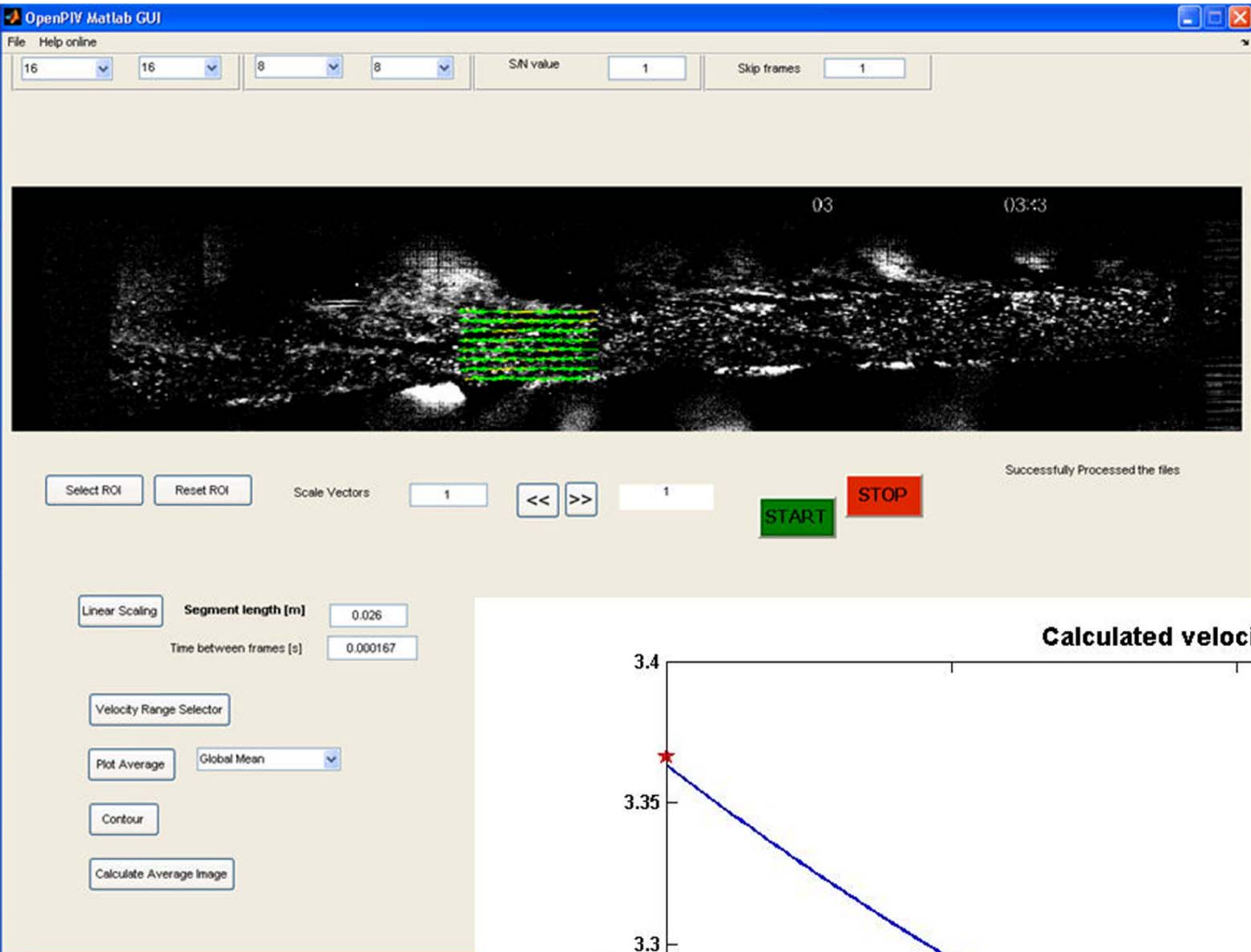
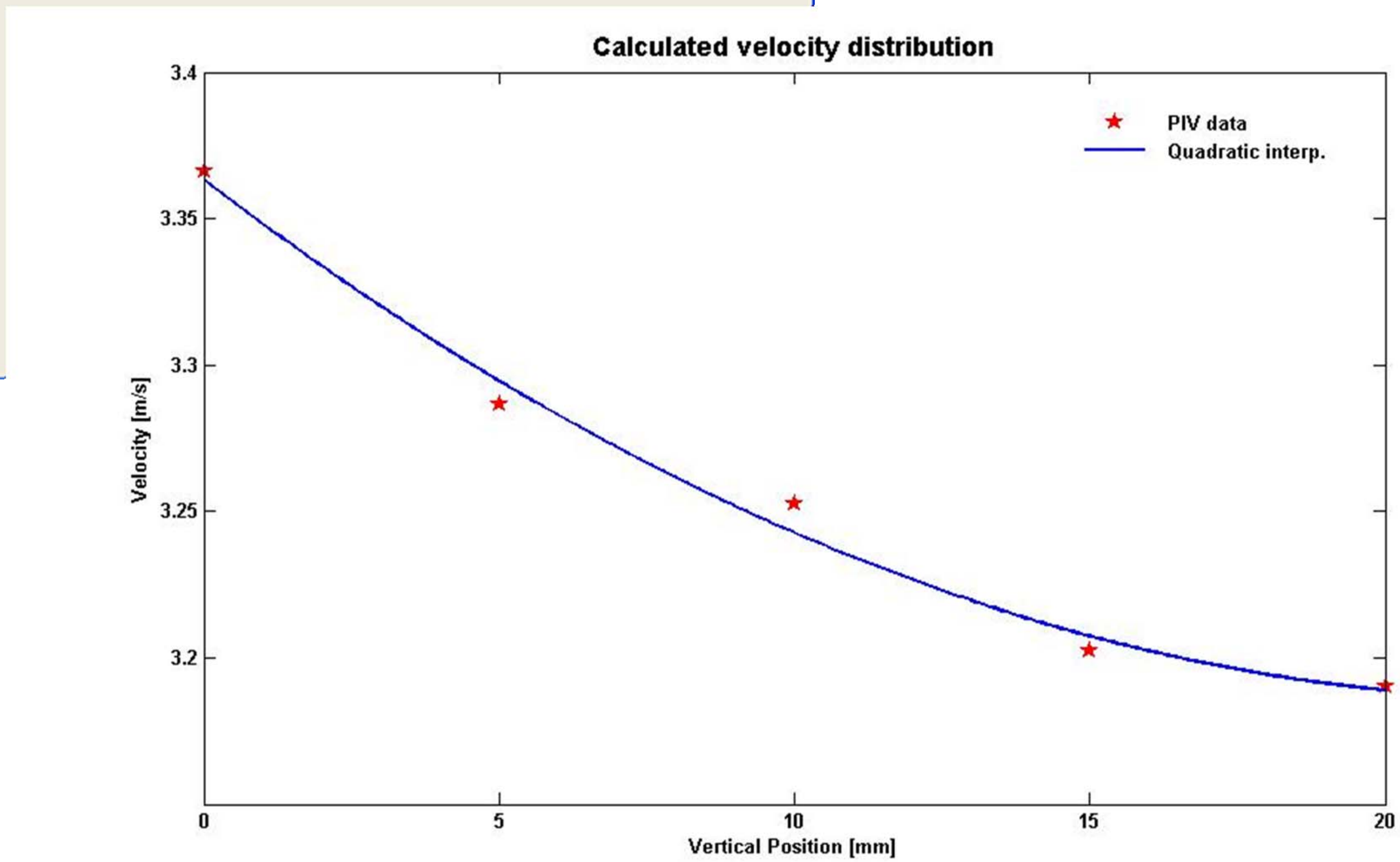


Particle Image Velocimetry

velocity distribution required to determine bulk density





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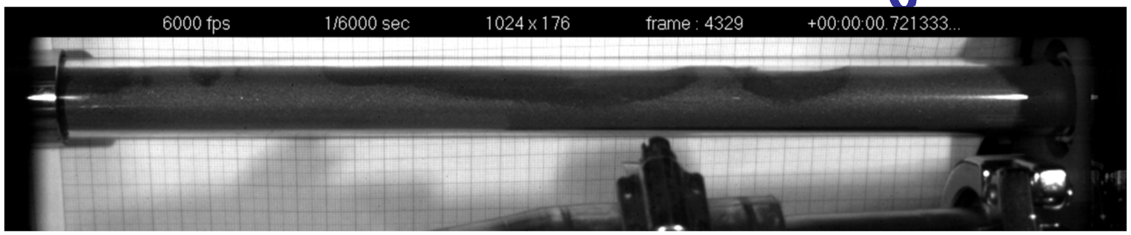
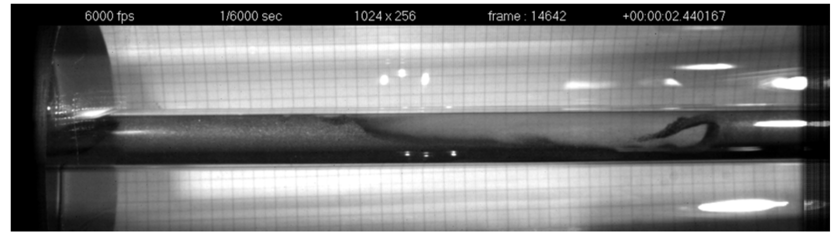
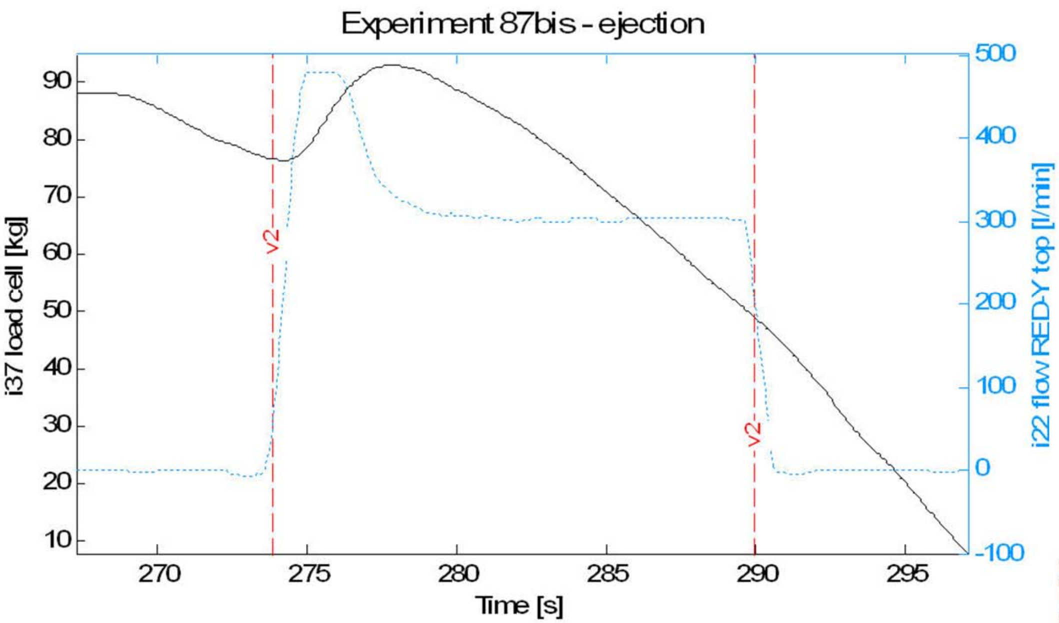
Variations in the flow rate – typical 2bar ejection



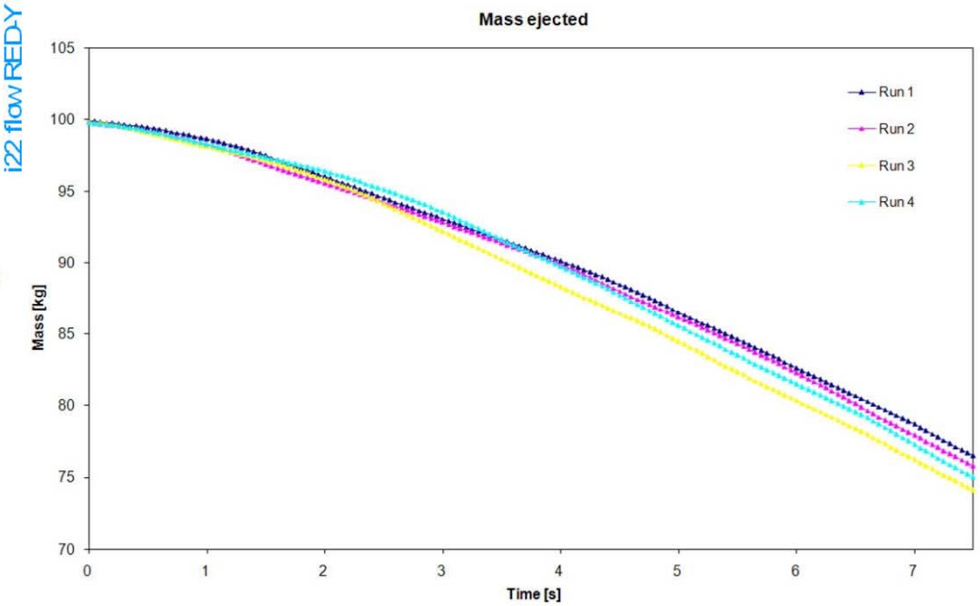




How much material would a proton beam interact with?

Bulk density?

Is the amount of material in the nozzle (or jet) constant?



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Erosion Monitoring

- Expect rig lifetime to be limited by wear
- Wall thickness monitoring:
  - Dense-phase hopper / nozzle
    - No damage
  - Lean-phase suction pipework
    - Straight vertical lift to avoid erosion
  - Deflector plates
    - So far so good
- Design to avoid erosion problems is critical
  - Lean phase optimisation (↓u, ↑ρ)
  - Avoid lean-phase bends ✓
  - Operate without discharge valve ✓
  - Replace deflector plate with powder/powder impact

Ultrasonic Thickness Gauge

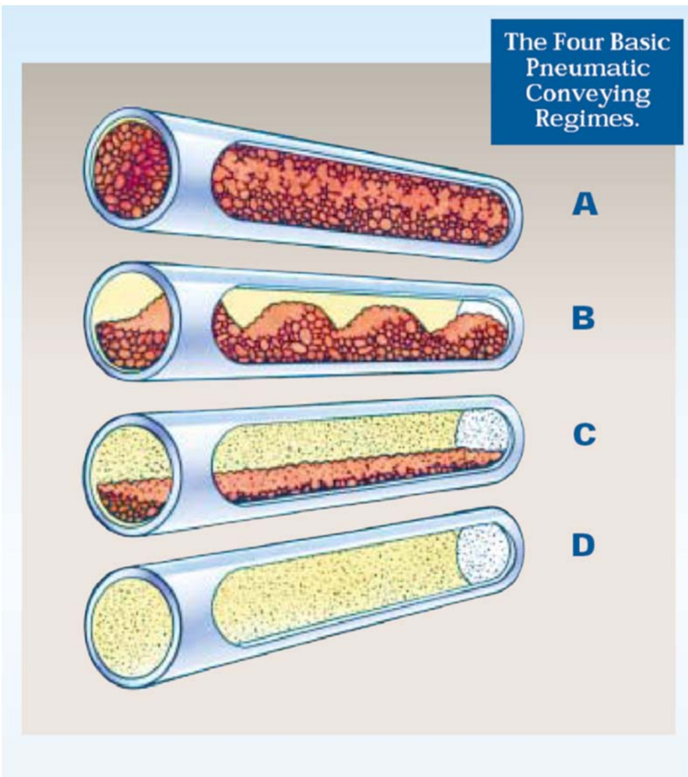
Material	Vickers Hardness
Stainless-steel 316L	140
Tungsten	360
Alumina (Al_2O_3)	1500
Boron Carbide (B_4C)	3200

Selected Material Hardness Values

Pneumatic Conveying Regimes

Low Velocity

Increasing Driver Pressure



High Velocity

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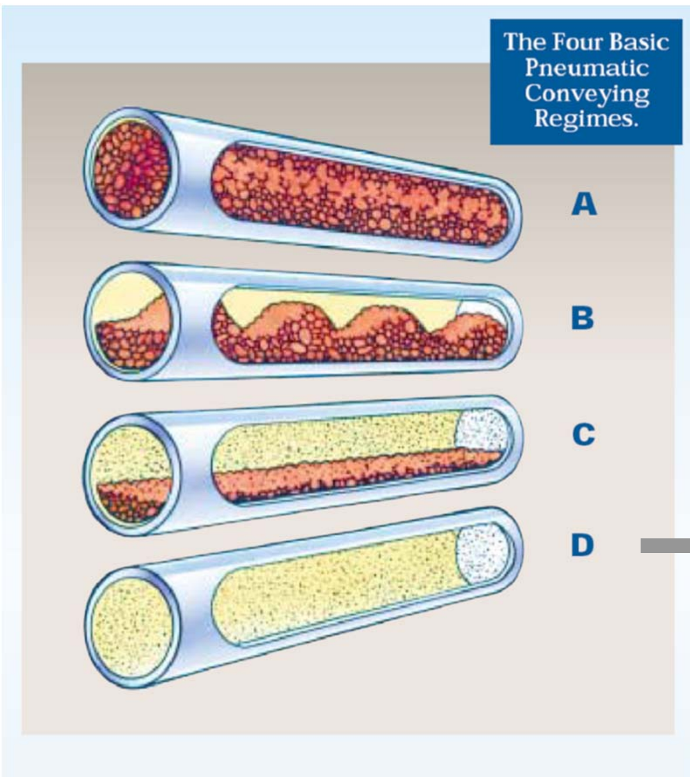


D. Lean Phase

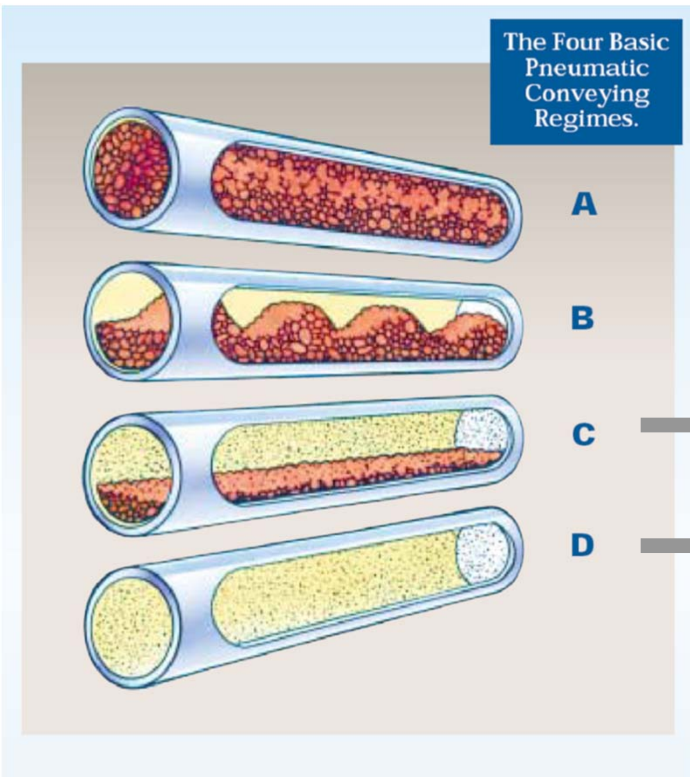
- Low fraction of solid material
- High velocity = erosion!
- Used in vacuum recirculation line

Pneumatic Conveying Regimes

Low Velocity

Increasing Driver Pressure

High Velocity



C. Continuous Dense Phase

- Pipeline part full of material
- Stable continuous flow
- Intermediate velocity

D. Lean Phase

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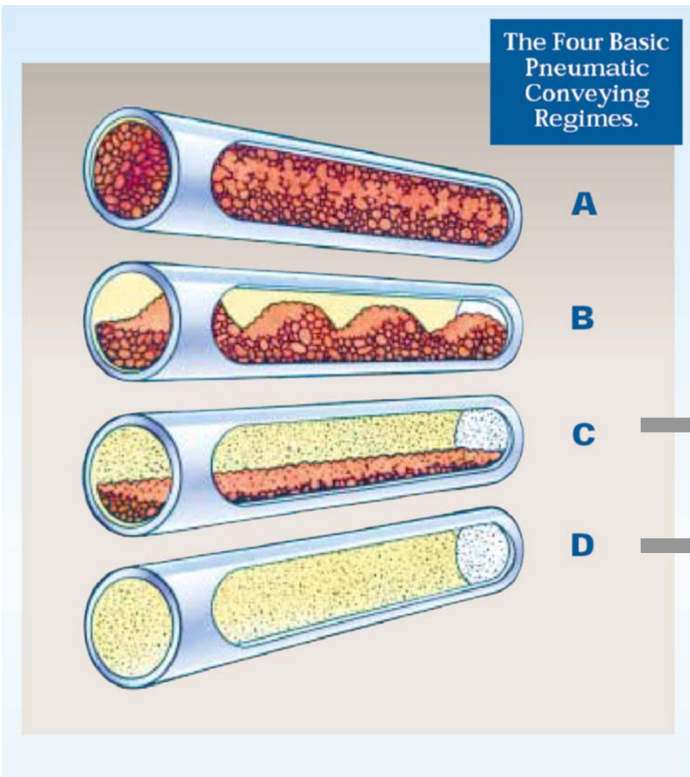

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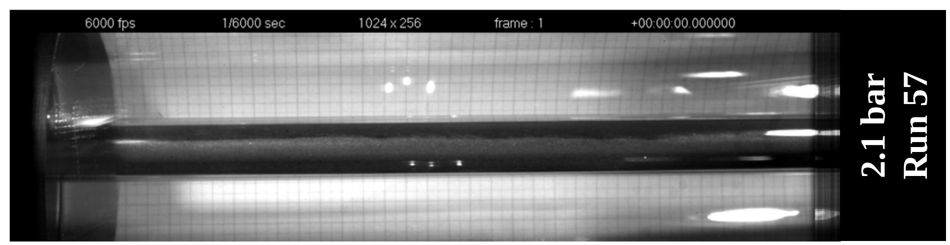

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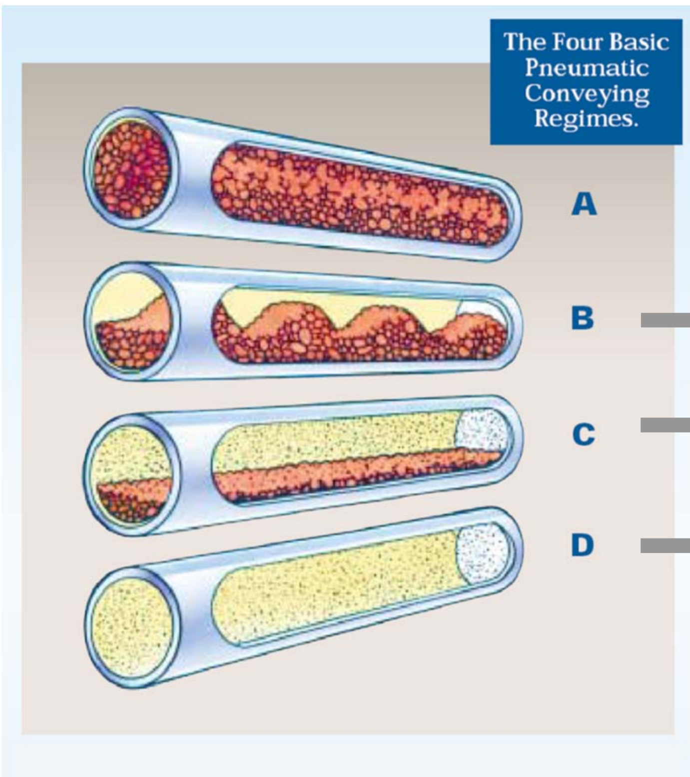
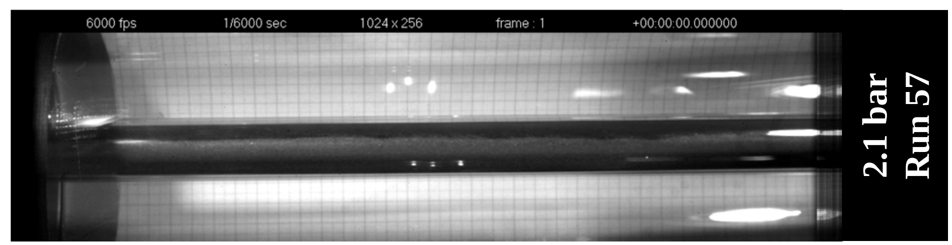


B. Discontinuous Dense Phase

- Pipeline almost full of material
- Unstable "plug flow"
- Intermediate velocity

C. Continuous Dense Phase



D. Lean Phase

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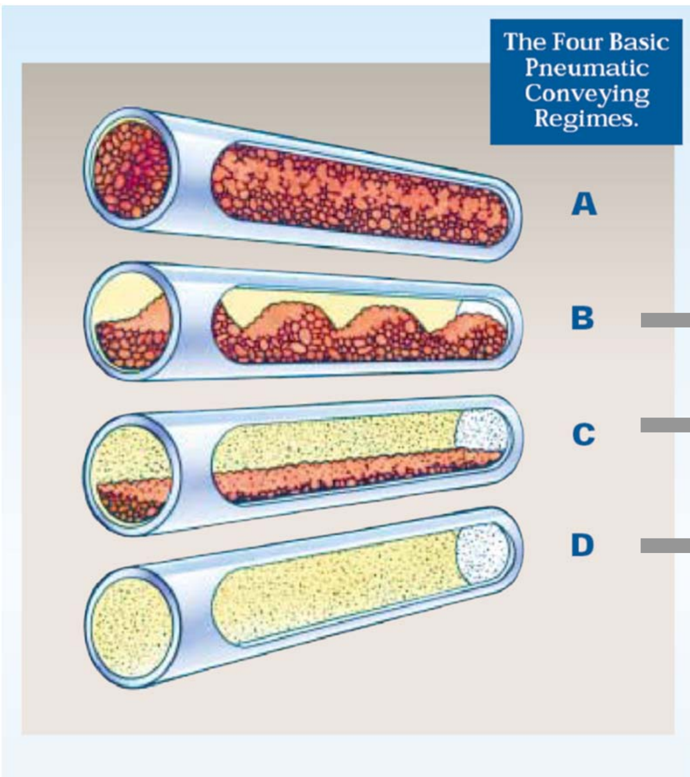
Low Velocity

Increasing Driver Pressure

High Velocity



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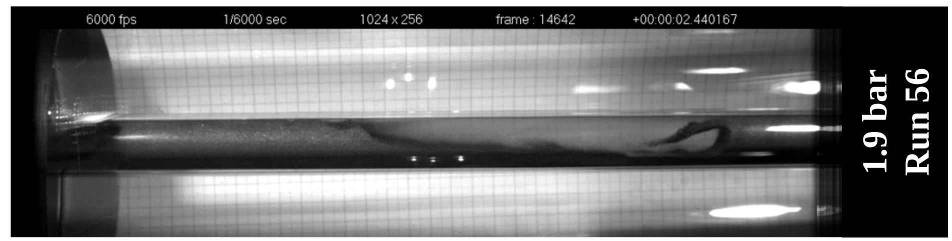

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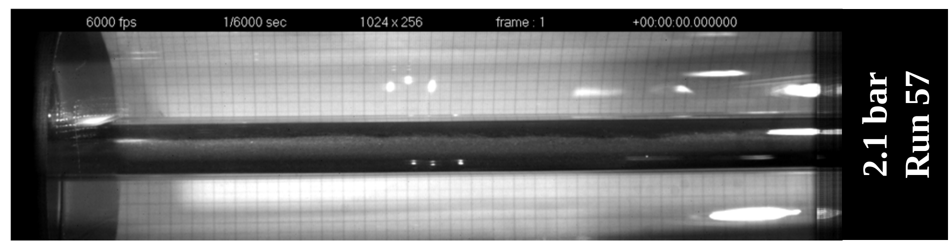

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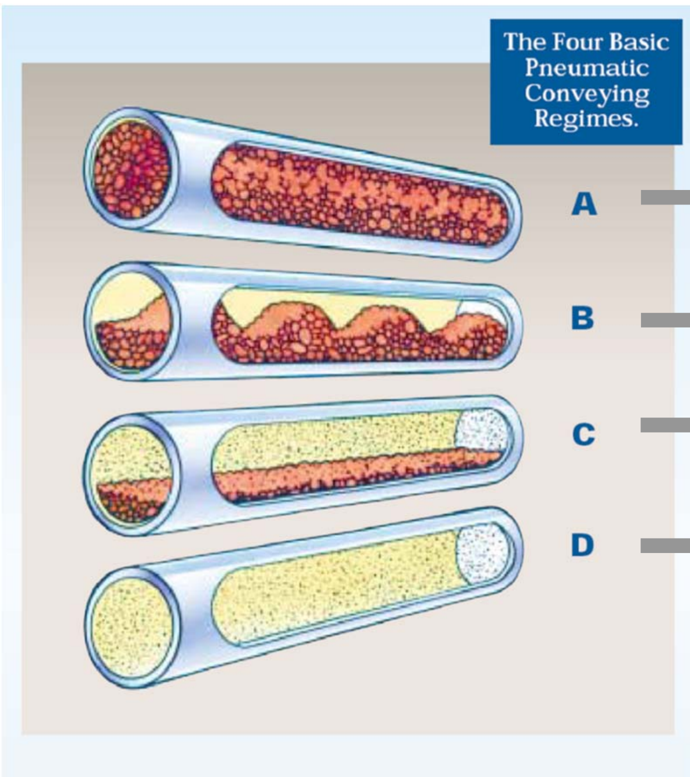
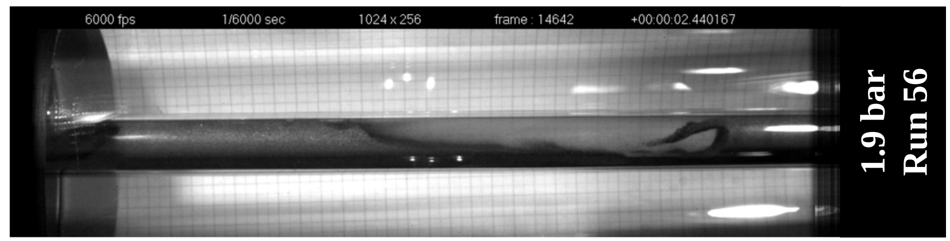


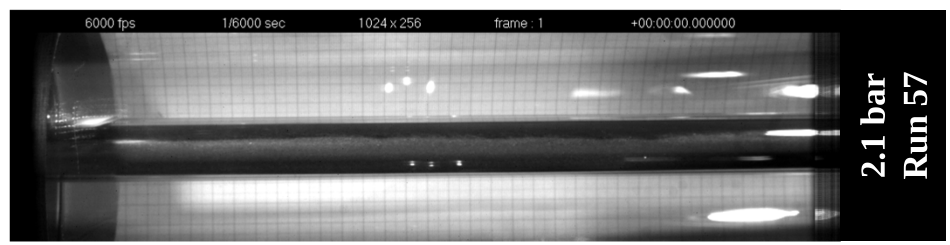
A. Solid Dense Phase

- Pipeline full of material, 50% v/v
- Low velocity
- Not yet achieved in our rig – further work

B. Discontinuous Dense Phase



C. Continuous Dense Phase



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High Power Targets

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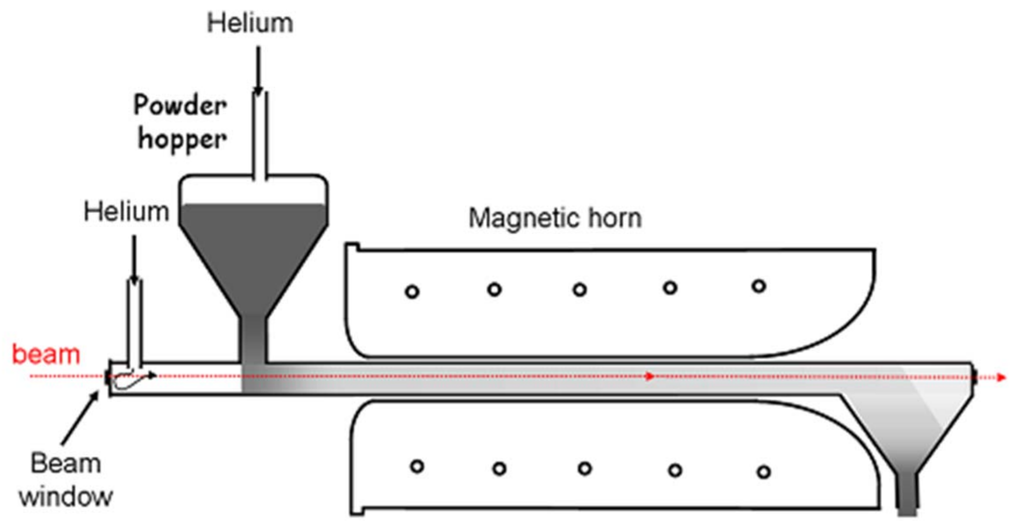
A Flowing Powder Target Layout Sketch
compatible with either solenoid or magnetic horn

- Potential powder target materials
  - Tungsten (W), ρ_{solid}19.3 g/cc
  - Titanium? (Ti), ρ_{solid}4.5 g/cc
  - Nickel (Ni), ρ_{solid}8.9 g/cc
  - Titanium Oxide (TiO_2), ρ_{solid}4.2 g/cc



Schematic layout of a flowing powder superbeam target

Flowing powder target: interim conclusions

- Flowability of tungsten powder
  - Excellent flow characteristics within pipes
  - Can form coherent, stable, dense open jet **(c.10 kg/s for 2cm dia)**
  - Density fraction of 42% ± 5% achieved ~ static bulk powder density
- Recirculation
  - Gas lift works for tungsten powder (so far **c. 2.5 kg/s**, 4 x slower than discharge rate.
  - **NB this is equal to discharge rate for new baseline 1 cm diameter target at 10 m/s**)
- Both contained and open powder jets are feasible
- A number of different flow regimes identified
- Design to mitigate wear issues is important for useful plant life – so far so good.
- No wear observed in any glass tubes used for discharge pipe tests

Flowing powder target: future work

- Optimise gas lift system for future CW operation
- Attempt to generate stable solid dense phase flow
- Investigate low-flow limit
- Carry out long term erosion tests and study mitigation
- Study heat transfer between pipe wall and powder
- Demonstrate magnetic fields/eddy currents are not a problem
  - Use of high field solenoid?
- Investigate active powder handling issues (cf mercury?)
- Demonstrate interaction with pulsed proton beam does not cause a problem
  - **Application to use HiRadMat facility at CERN has been submitted**

Input to the IDR

1. O. Caretta and C.J. Densham, RAL, OX11 0QX, UK; T.W. Davies, Engineering Department, University of Exeter, UK; R. Woods, Gericke Ltd, Ashton-under-Lyne, OL6 7DJ, UK, **PRELIMINARY EXPERIMENTS ON A FLUIDISED POWDER TARGET**, Proceedings of EPAC08, Genoa, Italy, WEPP161
2. C.J.Densham, O.Caretta, P.Loveridge, STFC Rutherford Appleton Laboratory, Chilton, Didcot, OX11 0QX, UK; T.W.Davies, University of Exeter, UK; R.Woods, Gericke Ltd, Ashton-under-Lyne, OL6 7DJ, UK **THE POTENTIAL OF FLUIDISED POWDER TARGET TECHNOLOGY IN HIGH POWER ACCELERATOR FACILITIES** Proceedings of PAC09, Vancouver, BC, Canada WE1GRC04
3. TW Davies, O Caretta, CJ Densham, R Woods, **THE PRODUCTION AND ANATOMY OF A TUNGSTEN POWDER JET**, Powder Technology 201 (2010) 296-300

Powder Technology
Volume 201, Issue 3, 12 August 2010, Pages 296-300

doi:10.1016/j.powtec.2010.03.018 | How to Cite or Link Using DOI

The production and anatomy of a tungsten powder jet

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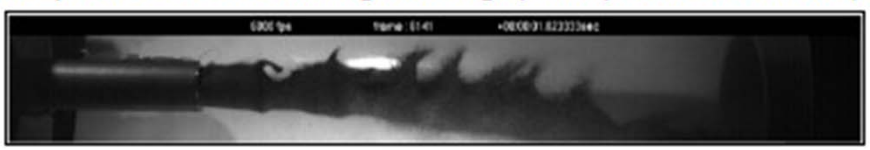
Received 5 June 2009; revised 17 March 2010; accepted 19 March 2010. Available online 30 March 2010.

Abstract

A tungsten powder jet is a potential candidate technology for a particle production target in a future high power (i.e. Multi-MW) particle accelerator based facility, such as a so-called conventional neutrino Super Beam, a proposed Neutrino Factory, or a future neutron source. To test the viability of producing a suitable powder jet a few simple experiments were performed using standard pneumatic conveying equipment and the encouraging results are presented.

Graphical abstract

This paper describes some preliminary studies of the production of a horizontal jet of powdered tungsten undertaken to investigate the viability of such a jet for use as a beam target in a high power particle accelerator (The Neutrino Factory Project).



Unstable tungsten powder jet leaving a 20 mm ID cylindrical nozzle

Hig

Po

Keywords: Jet flow; Tungsten; Powder jet; High power target; Neutrino factory

Targets

And Finally

Live demonstration of tungsten power jet today in R12 at 3:30 today