

The Potential of Fluidised Powder Target Technology in High Power Accelerator Facilities

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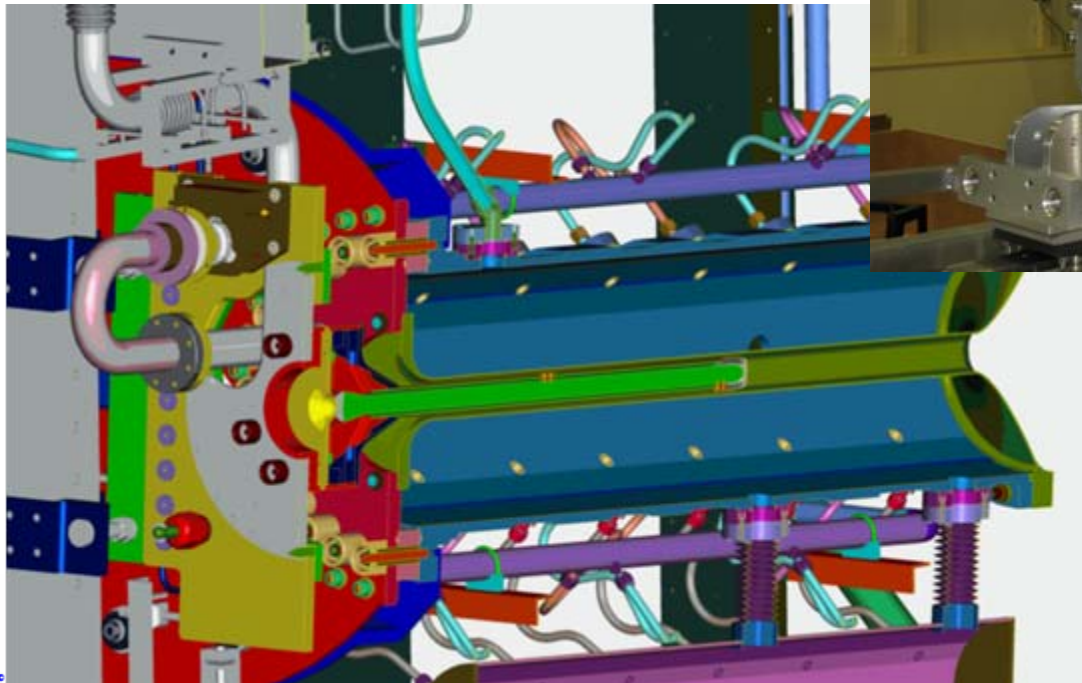
Motivations: what are the limits for solid targets?

E.g. T2K Graphite target for 750 kW operation?

Pion production target installed inside magnetic horn for 'conventional' neutrino beam ($\nu_\mu \rightarrow \nu_e$ oscillations)

First Beam: 23rd April 2009

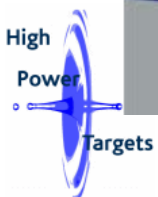
Phase I :30 GeV, 750 kW beam



5 year roadmap: 1.66 MW

Ultimate: 3-4 MW

Target options?



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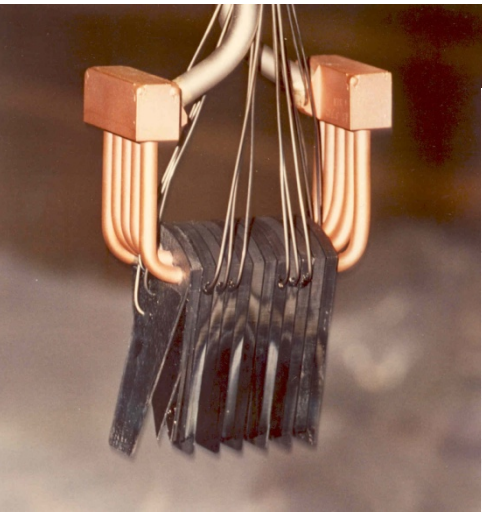


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Powers and power densities in a few target systems using proton accelerator drivers

| | Material | Proton beam energy | Power in target kW | Peak power density J/cc/pulse | Pulse length |
|------------------------------------|------------------------|--------------------|-----------------------|----------------------------------|---------------------------|
| T2K (JPARC) Phase 1 | Graphite | 30-50 GeV | 30 | 344 | 5×10^{-6} s |
| Neutrino Factory | Hg jet or tungsten | 5-15 GeV | 1000 | 300 | Few $\times 10^{-9}$ s |
| SNS (ORNL)/ J-SNS (JPARC) | Contained Liquid Hg | 1 GeV | 1400 | 10 | 10^{-6} s |
| | | 3 GeV | 1000 | 17 | |
| Pbar (FNAL) | Ni, ++ | 120 GeV | 200 | 25000 | 5×10^{-9} s |

Broken graphite targets / samples from existing accelerator facilities



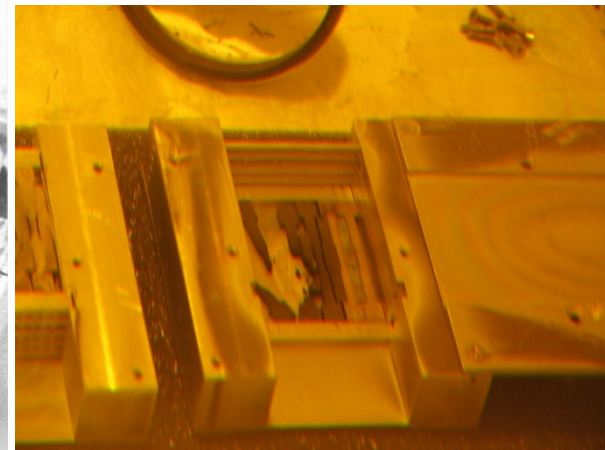
LAMPF



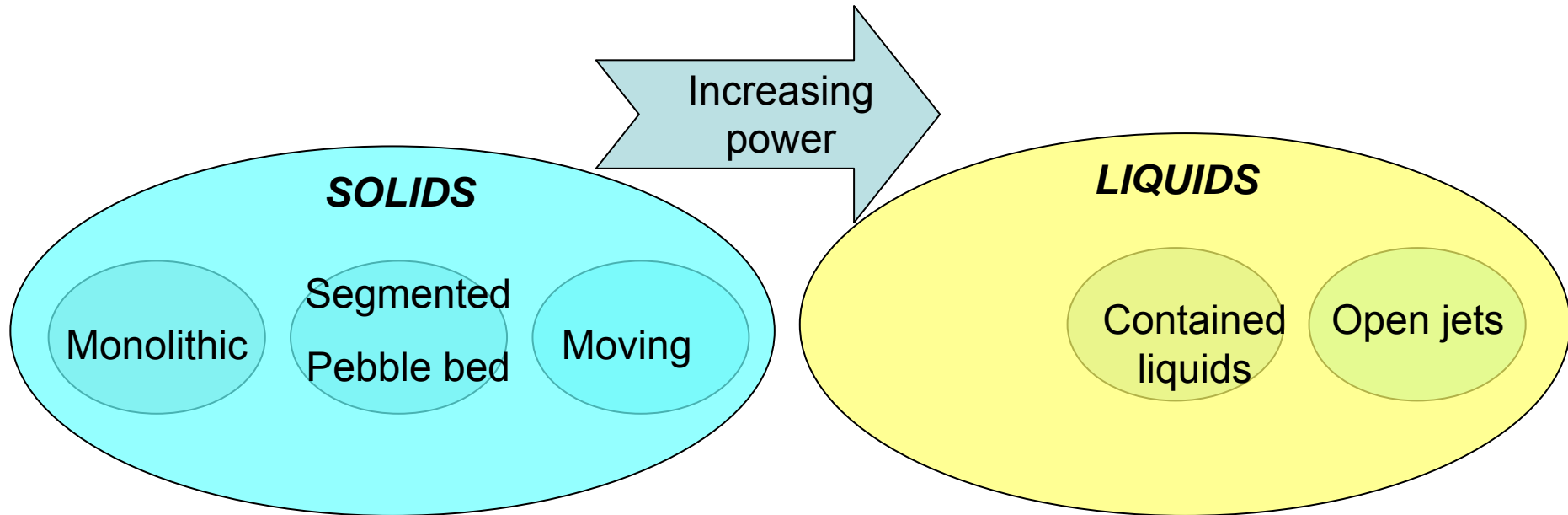
PSI



BNL



Target technology progression:



Challenges:

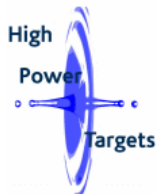
Power
dissipation,
Radiation
damage,
Shock waves/
thermal stress

Power
limits,
Low
density

Cooling,
Lubrication
/ tribology,
Reliability

Shock waves,
Cavitation
Corrosion
Radiochemistry

Splashing,
radiochemistry,
corrosion

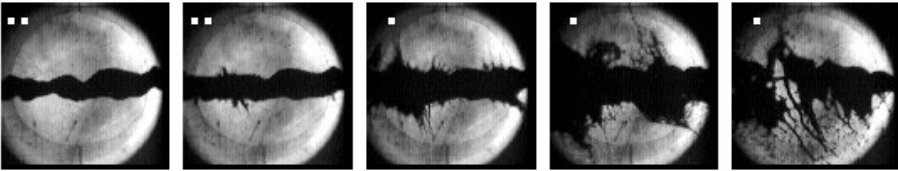


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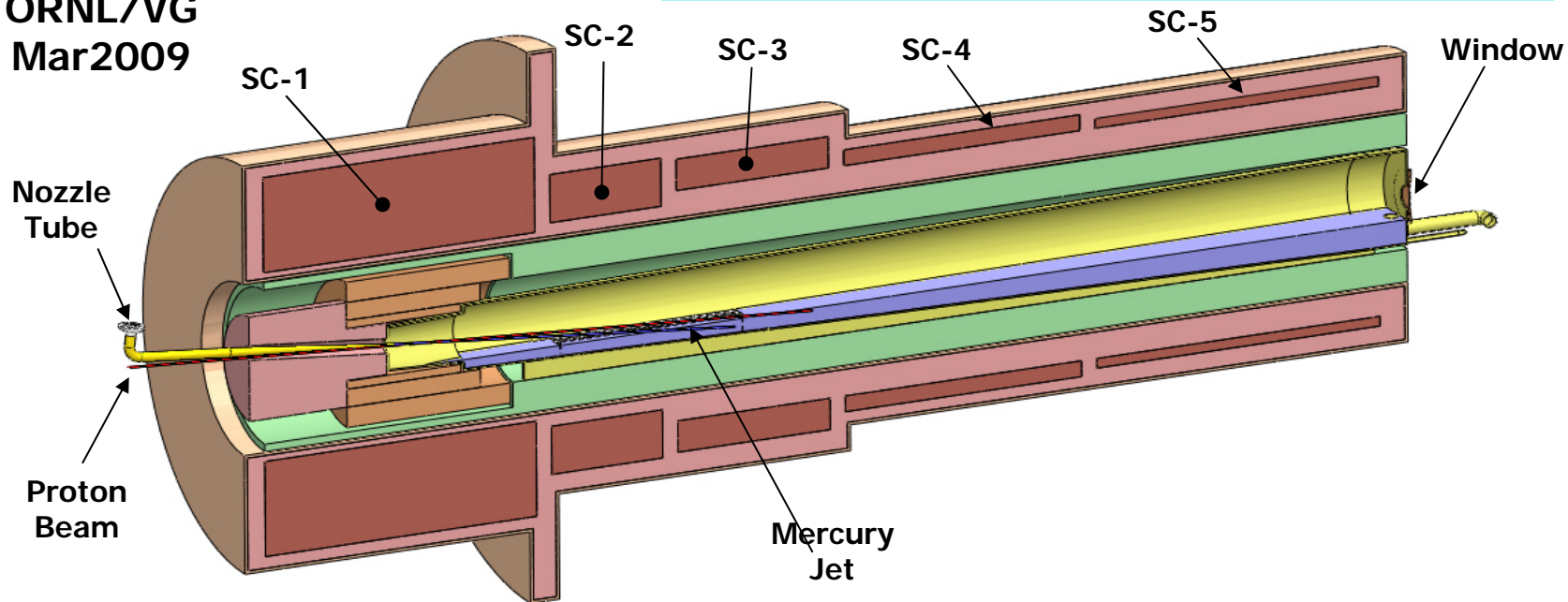
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Mercury jet target is 'already broken' - Neutrino Factory / Muon Collider baseline



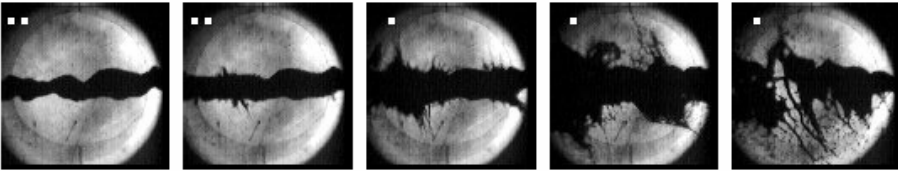
... pulsed beam 'splash' mitigated by solenoidal magnetic field (ref. MERIT experiment talk by Kirk MacDonald)

ORNL/VG
Mar2009



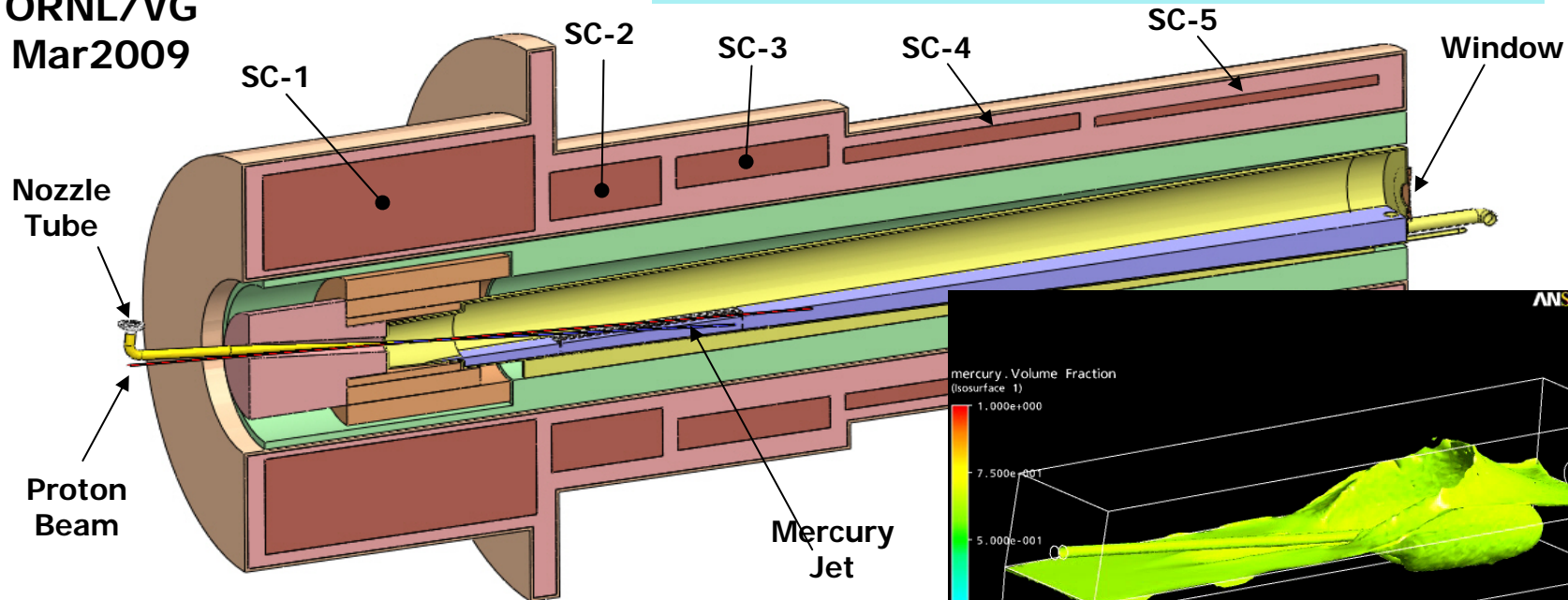
Some issues remain
e.g. interaction of jet
with mercury pool

Mercury jet target is 'already broken' - Neutrino Factory / Muon Collider baseline

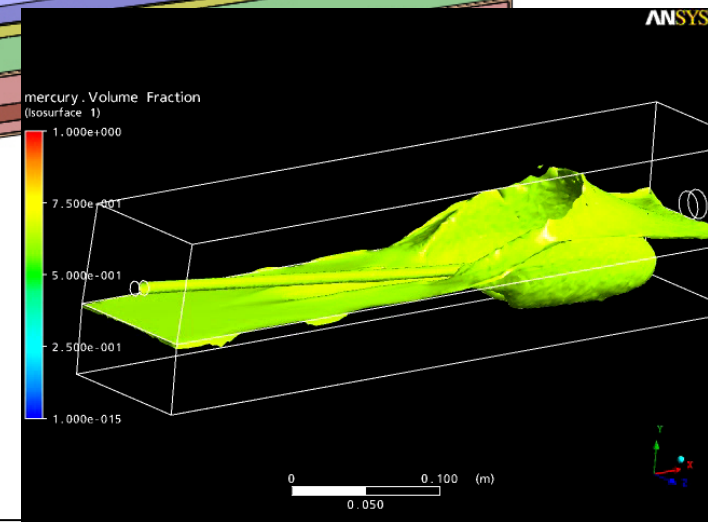


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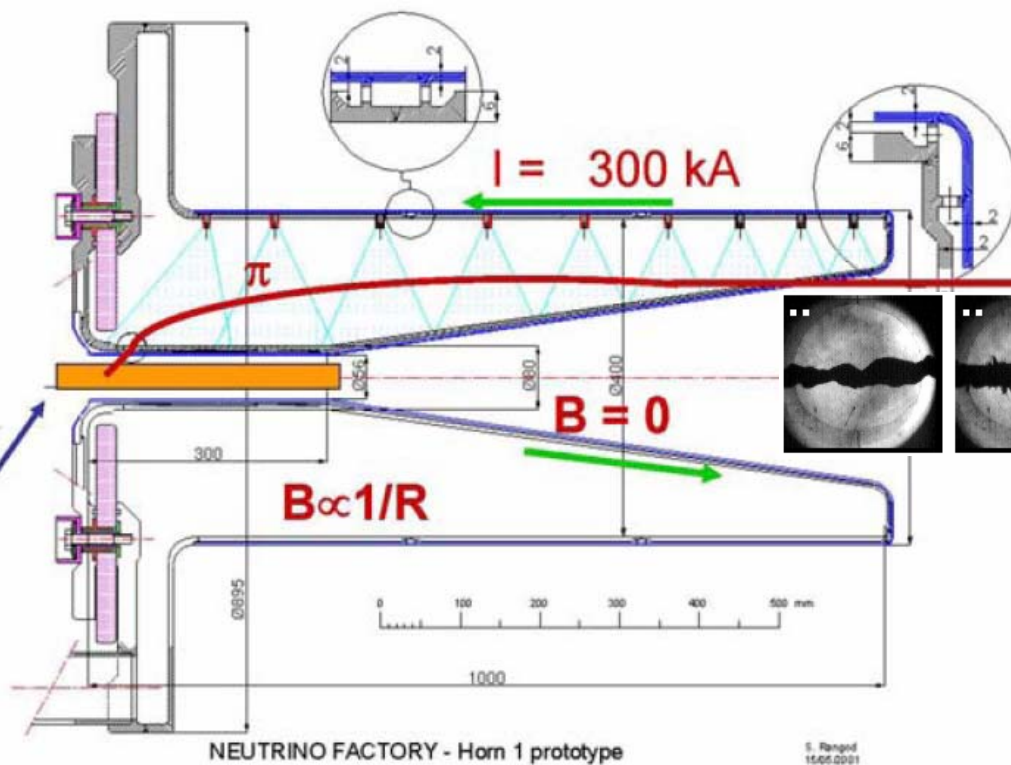


Liquid metal jets with magnetic horns? Probably not...

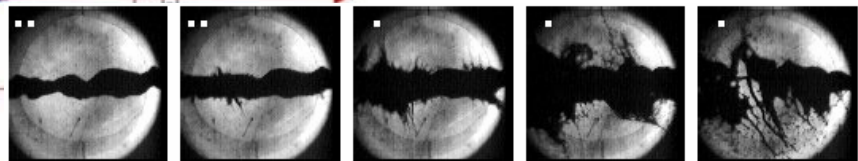
2.2 GeV
at 4MW
50 Hz
operation

Protons

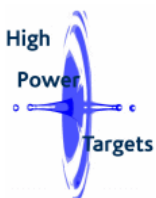
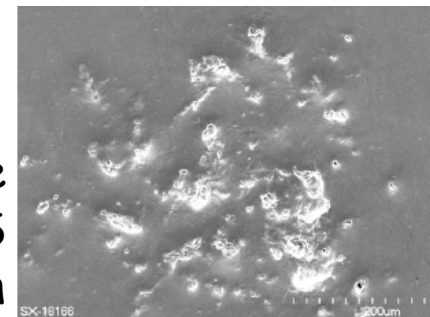
Hg Jet



No magnetic field
inside a magnetic
horn, so
no damping of
splashes



Cavitation Damage
Erosion from SNS/JSNS
research

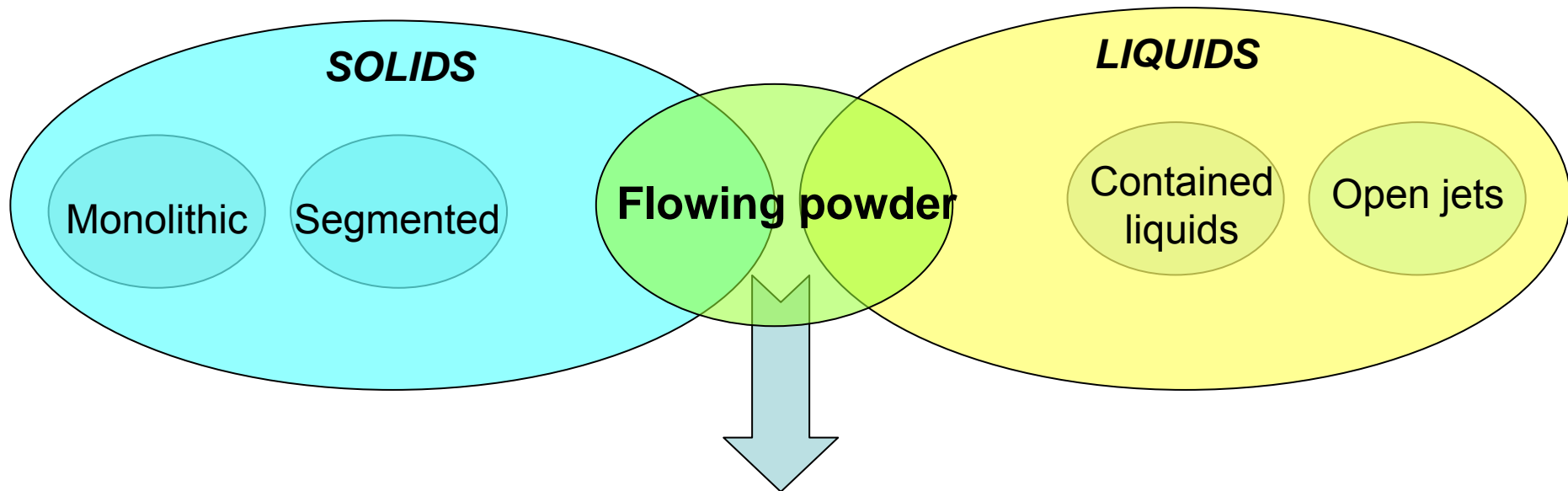


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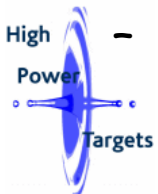
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Is there a 'missing link' target technology?

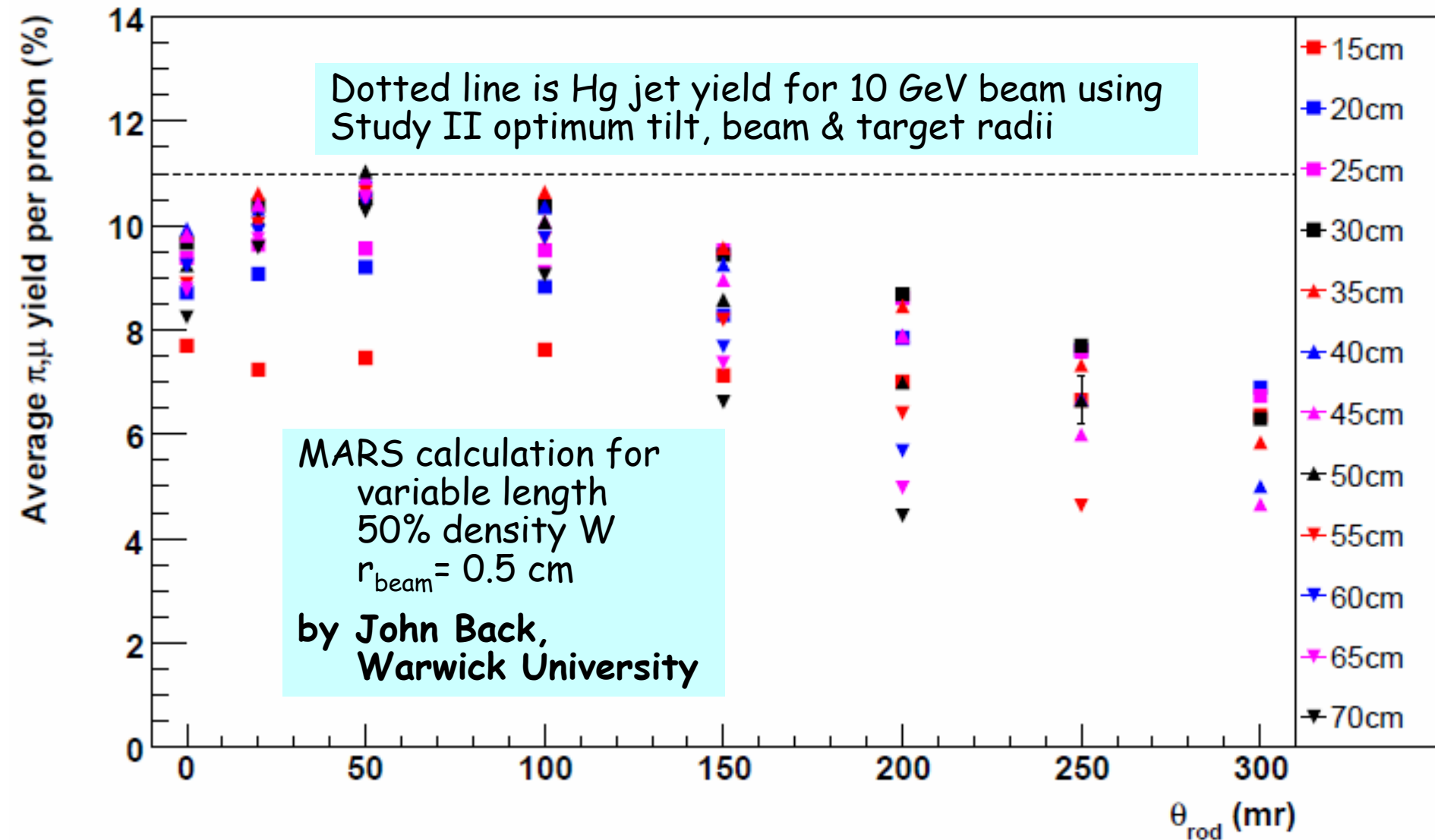


Flowing powder targets: some potential advantages

- **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 i.e. cheaply!

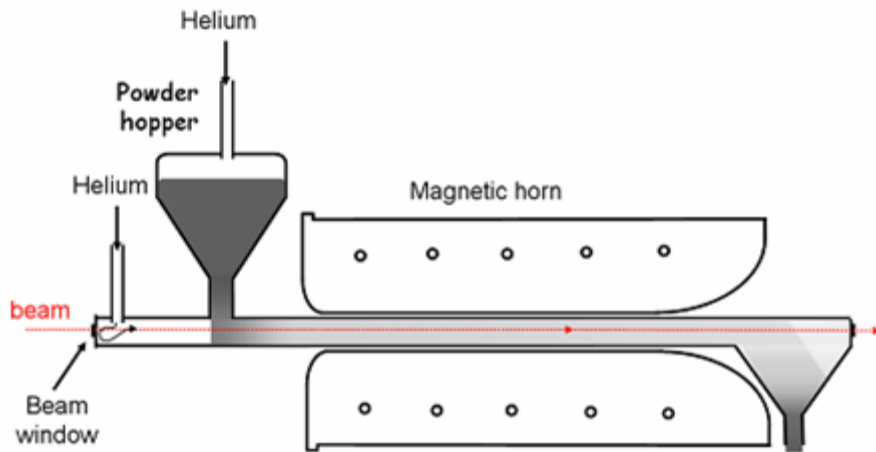


Pion+muon production for 50% W powder vs 100% Hg

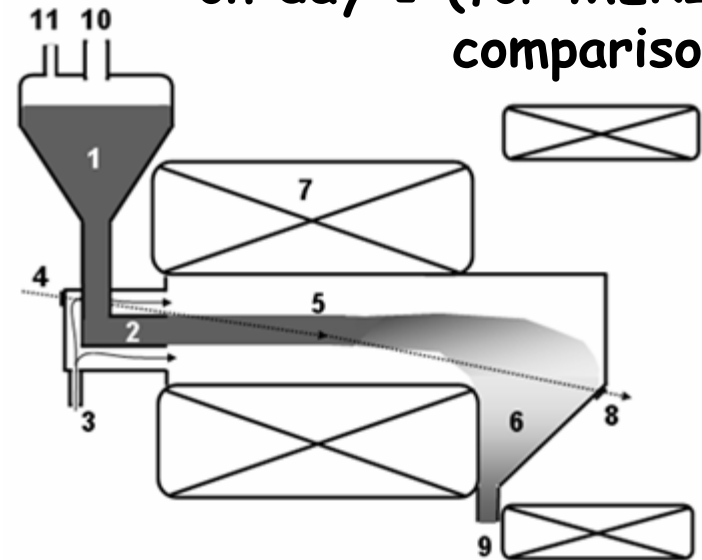


Schematic layouts of flowing powder targets for neutrino facilities

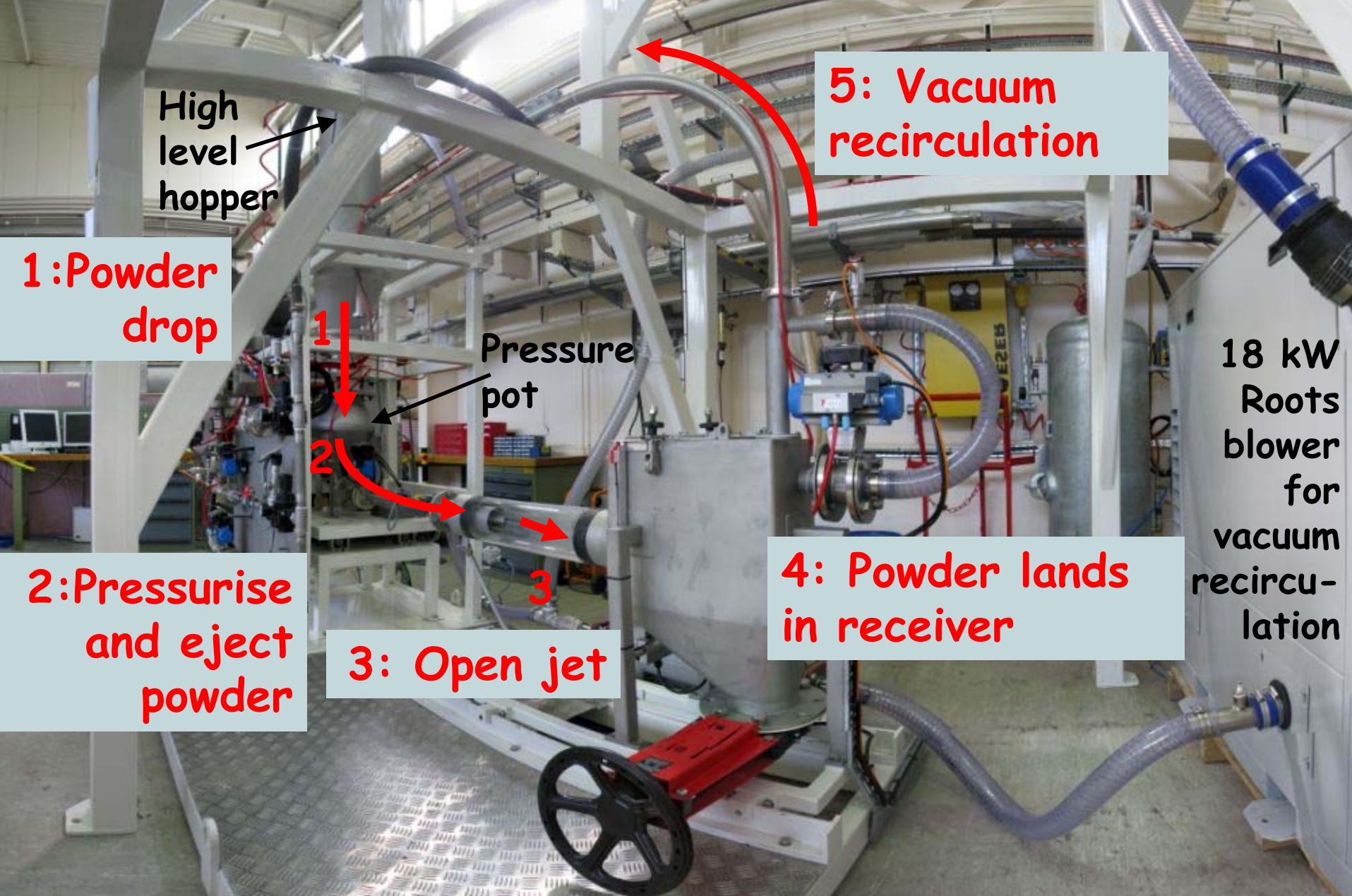
Superbeam target - contained within pipe



Neutrino factory target - open jet configuration used in test rig on day 1 (for MERIT comparison)



(1) pressurised powder hopper, (2) discharge nozzle, (3) recirculating helium to form coaxial flow around jet, (4) proton beam entry window, (5) open jet interaction region, (6) receiver, (7) pion capture solenoid, (8) beam exit window, (9) powder exit for recirculation, (10) return line for powder to hopper, (11) driver gas line

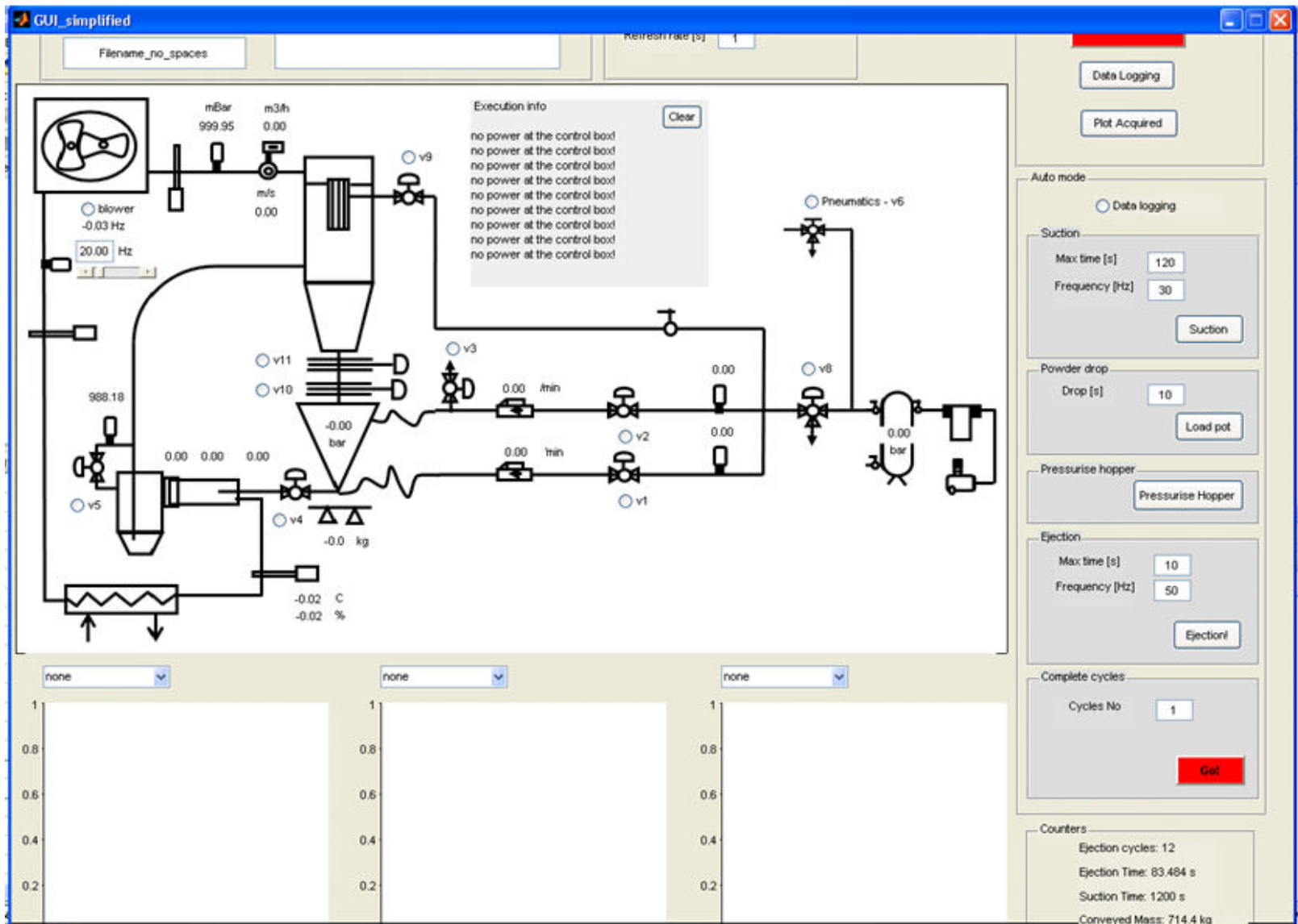


Powder test rig: open jet configuration

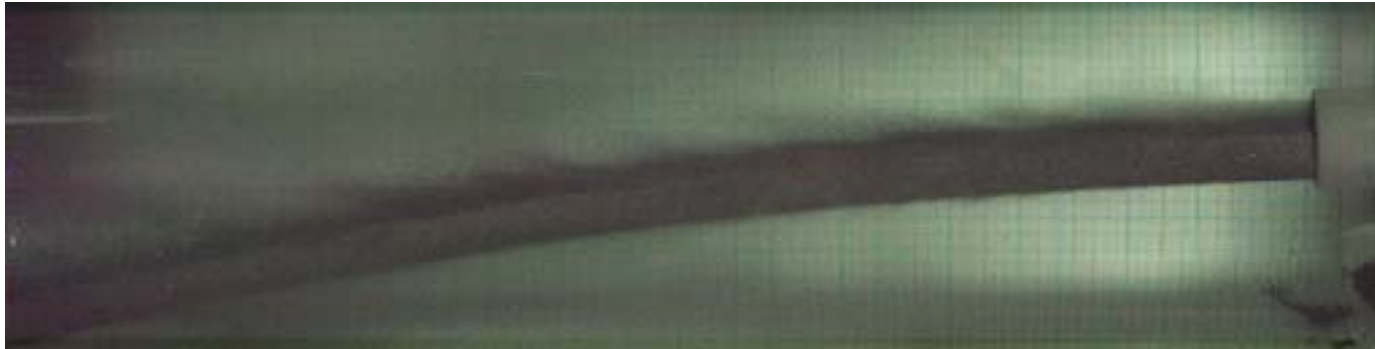
Overview of Powder Test Rig operation

- Powder recirculated in “Batch” mode
 - Rig contains ~130 kg Tungsten Powder
 - Discharge pipe ~20 mm diameter x 1 m long
 - Particle size < 250 microns
- Fully automated control system
 - Valve open/close sequence
 - Blower on/off
 - Blower Frequency
 - Data Logging
 - Hard-wired safety interlocks

GUI for Powder plant Control System

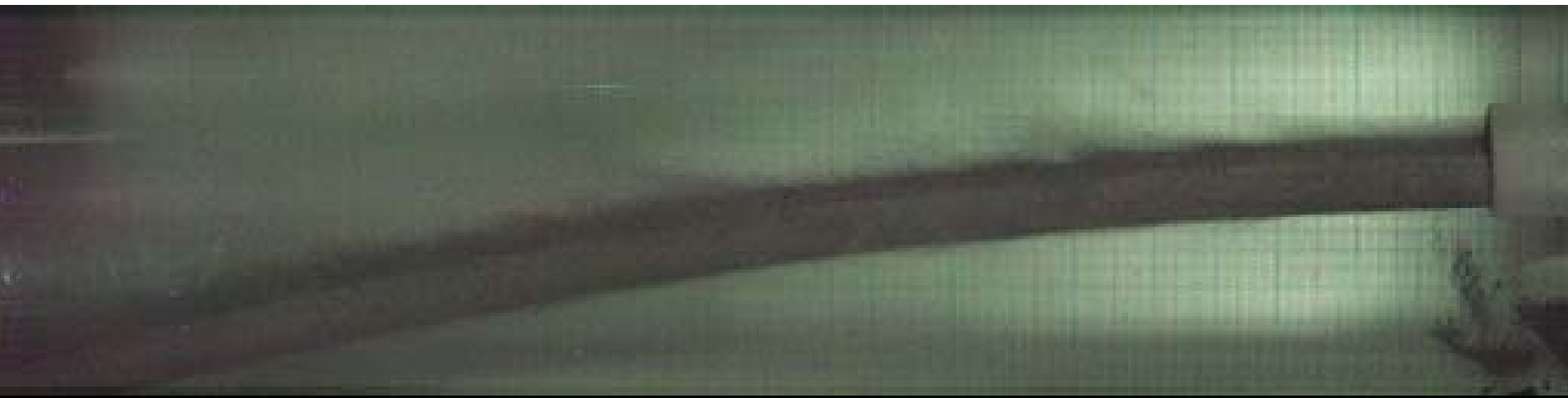


First data runs in March 2009



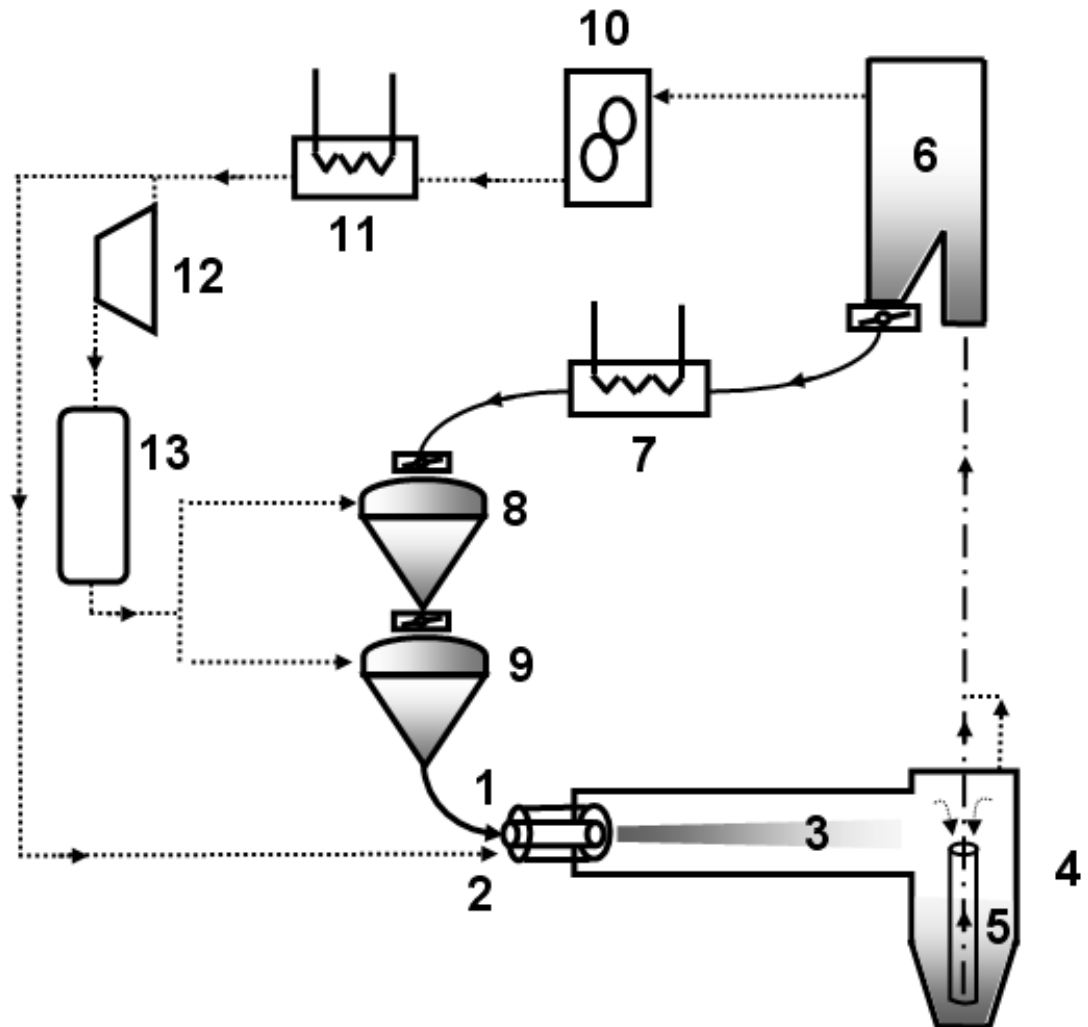
- 31 injection cycles - 3000 kg powder re-circulated
 - Driving pressure range 2 - 5 bar
- Best quality jet obtained for 2 bar driving pressure
 - Jet Velocity = 3.7 m/s
 - Stable Jet
 - Constant pressure in hopper throughout ejection
 - Constant velocity (top/bottom and over time)
 - Constant dimensions (with distance from nozzle and time)
- Jet material fraction = 42% ± 5% ~ bulk powder density at rest

Driving pressure = 2 bar
Jet velocity = 3.7 m/s
Material fraction ~ 42%



CW operation: schematic circuit outline

- (1) powder discharge nozzle
- (2) gas return line forming coaxial flow
- (3) target jet,
- (4) receiver hopper
- (5) suction nozzle for gas lift
- (6) gas lift receiver vessel with filter
- (7) powder heat exchanger
- (8) and (9) pressurised powder hoppers
- (10) Roots blower
- (11) gas heat exchanger
- (12) compressor
- (13) gas reservoir



Flowing powder target: future work

- Optimise gas lift system
- Carry out long term erosion tests and study mitigation
- Investigate low-flow limit
- Study heat transfer between pipe wall and powder
- Demonstrate shock waves are not a problem
 - Possibility to use test facility for shock wave experiment on a powder sample in helium environment?
- Demonstrate magnetic fields/eddy currents are not a problem
 - Use of high field solenoid?
- Investigate active powder handling issues (cf mercury?)

Flowing powder target: interim conclusions

- Flowability of tungsten powder
 - Excellent flow characteristics within pipes
 - Can form coherent, stable, dense open jet
 - Density fraction of $42\% \pm 5\%$ achieved ~ static bulk powder density
- Recirculation
 - Gas lift works for tungsten powder (though so far 10 x slower than discharge rate)
- Both contained and open powder jets are feasible