Thin liquid lithium targets for high power density applications: heavy ion beam strippers and beta beam production

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4th High Power Targetry Workshop

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Hilton Malmö City

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Outline

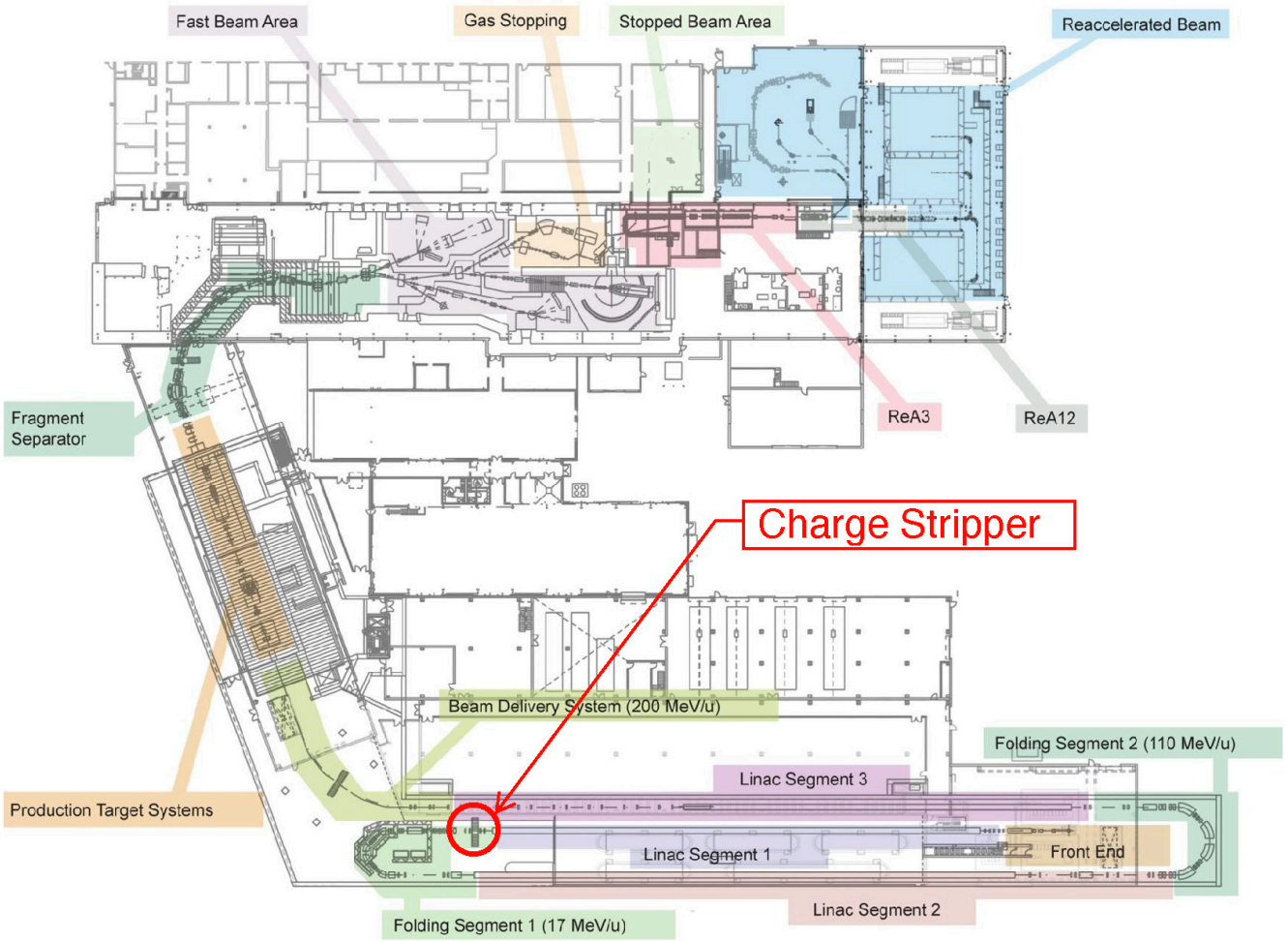
- Liquid Lithium Stripper idea for FRIB
- Brief theory of film stability
- Hardware description
- Status before FRIB
- Improvements for FRIB
- E-beam thickness measuring system
- Thickness measurement results
- Next Steps
- Beta-beams

Liquid Lithium Stripper for FRIB:

Advantages

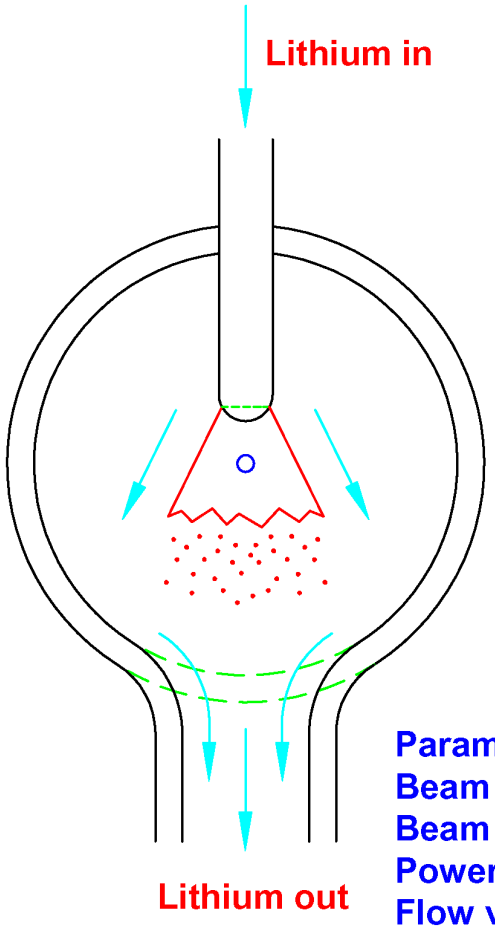
- High charge state
- High velocity flow ~60 m/s
- High heat capacity of Li
- Absorbs power deposited by the heavy ions
  - ***P*** ~600 W to ~1000 W
  - ΔT ~150 to ~420 °C
- May have unlimited lifetime

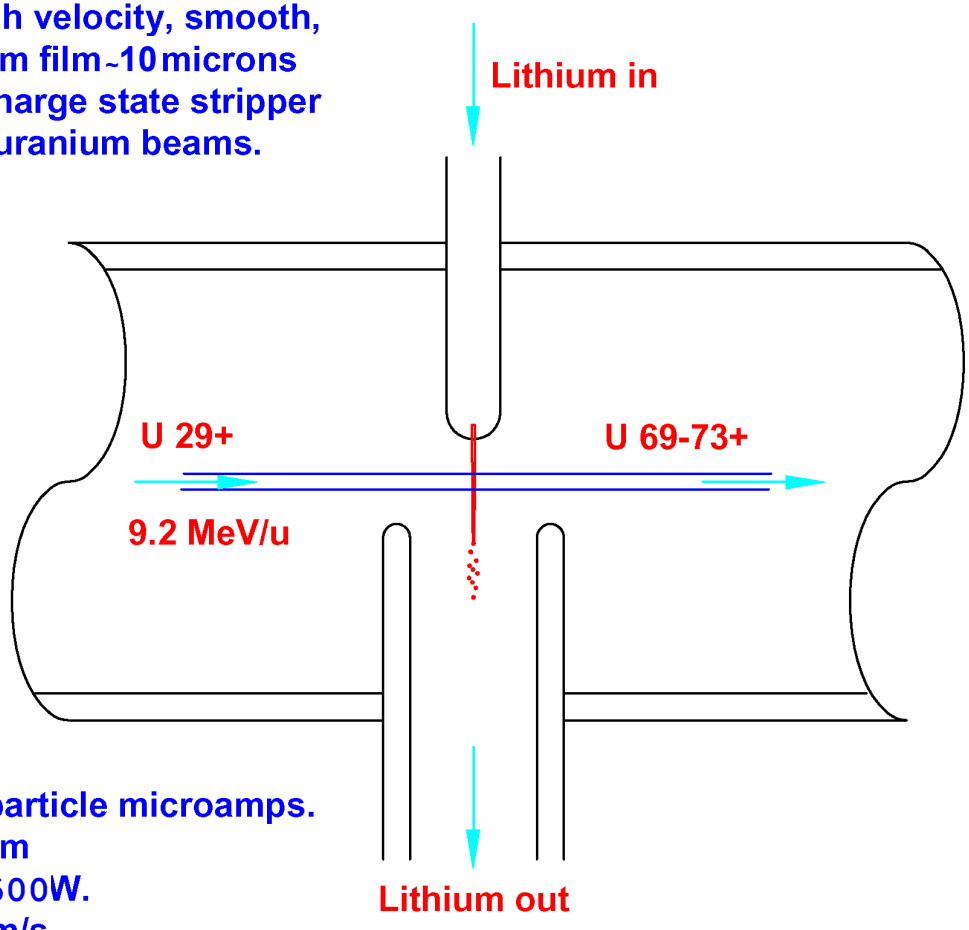
CD-1 Conceptual Design – [2]



Concept for FRIB Thin Liquid Lithium Stripper Film

Problem:
Develop high velocity, smooth, stable lithium film ~10 microns thick as a charge state stripper for intense uranium beams.

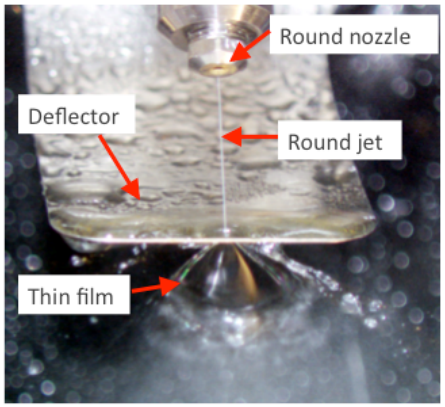




Parameters:
Beam current: 1.5 particle microamps.
Beam diameter 1 mm
Power deposited ~500W.
Flow velocity: ~60 m/s.
Peak temperature rise: ~400 C.

Introduction

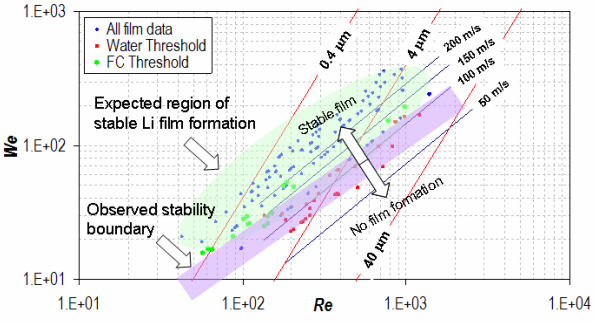
- **Development of a thin liquid lithium film is divided into three steps:**



1. Experimentally develop a liquid thin film formation scheme,

2. Experimentally develop of a film stability diagram for the film production scheme using water & a fluorocarbon liquid,

   This diagram will provide the range of design parameters, such as film thickness and velocity, that are potentially capable of producing a stable, smooth liquid lithium film.



3. Experimentally demonstrate formation of a thin film liquid lithium jet and confirm that the film is appropriate to be used as a stripper (thickness, film stability, size, and velocity etc).

Introduction

Approach to thin film production

- Forces on flowing Li film in vacuum:
  - Inertia (IF)
  - Surface tension (SF)
  - Viscosity (VF)
- Reynolds number (Re) ~ IF/VF
- Weber number (We) ~ IF/SF
- Empirically determine film stability in We vs Re plane

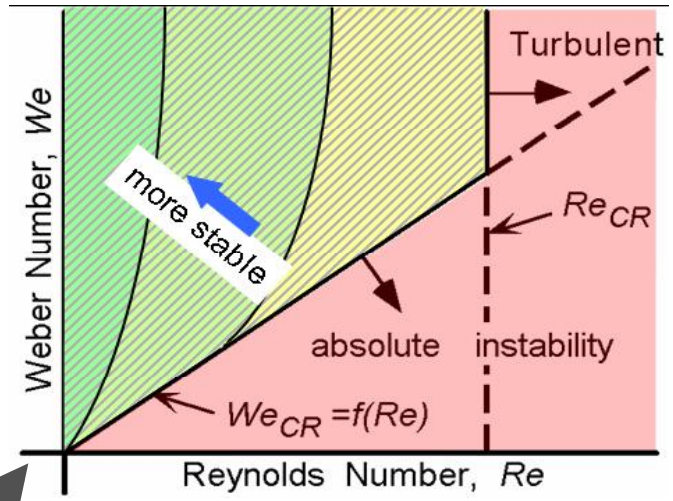
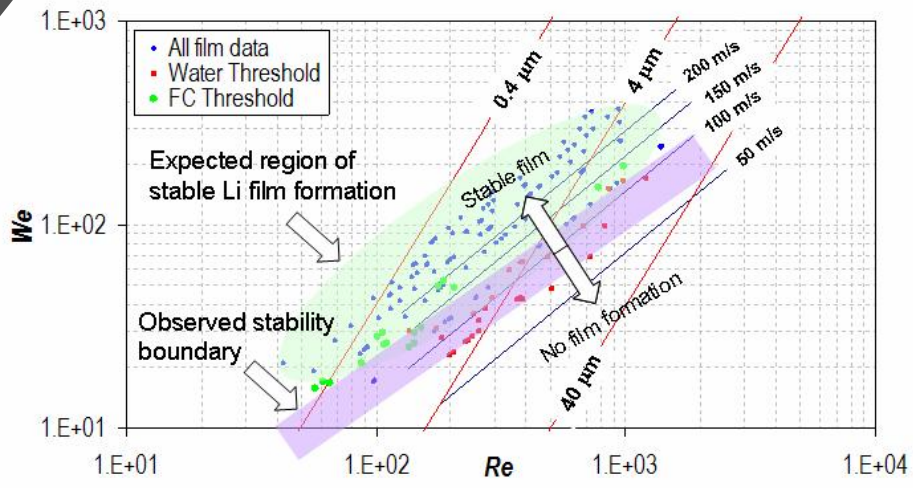


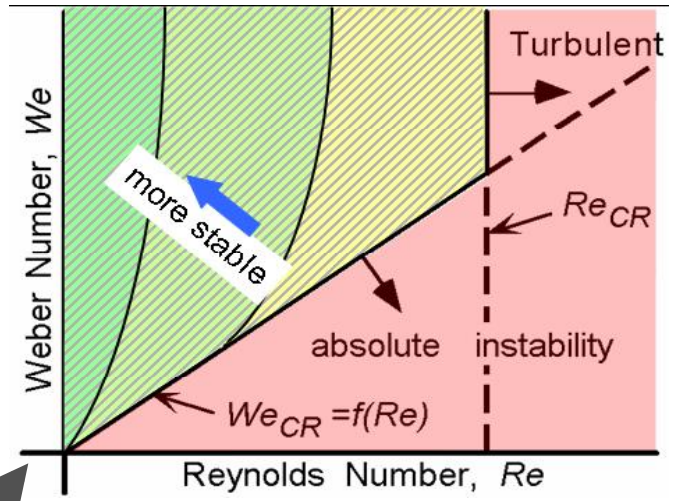
Figure 1. Schematic Representation of Stability Diagram for the Jet in Vacuum.



Introduction

Approach to thin film production

- Forces on flowing Li film in vacuum:
  - Inertia (IF)
  - Surface tension (SF)
  - Viscosity (VF)
- Reynolds number (Re) ~ IF/VF
- Weber number (We) ~ IF/SF
- Empirically determine film stability in We vs Re plane
- Use water & fluorinert to scope stable region



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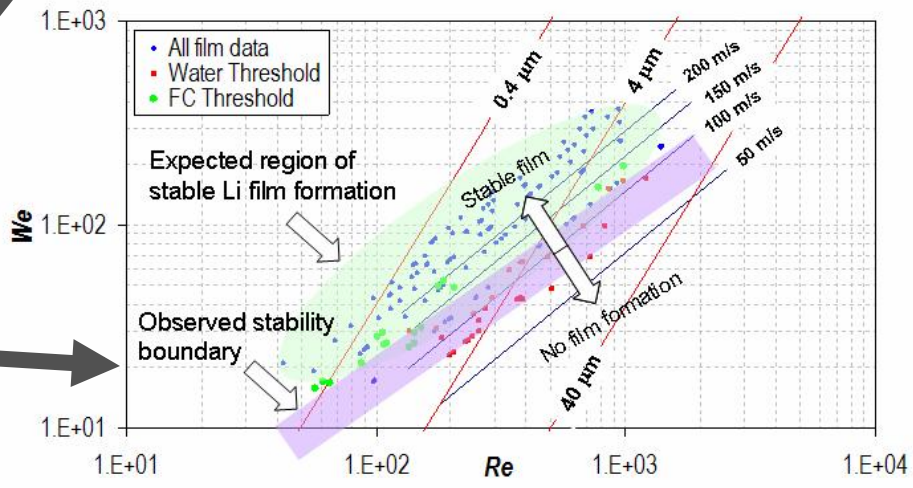
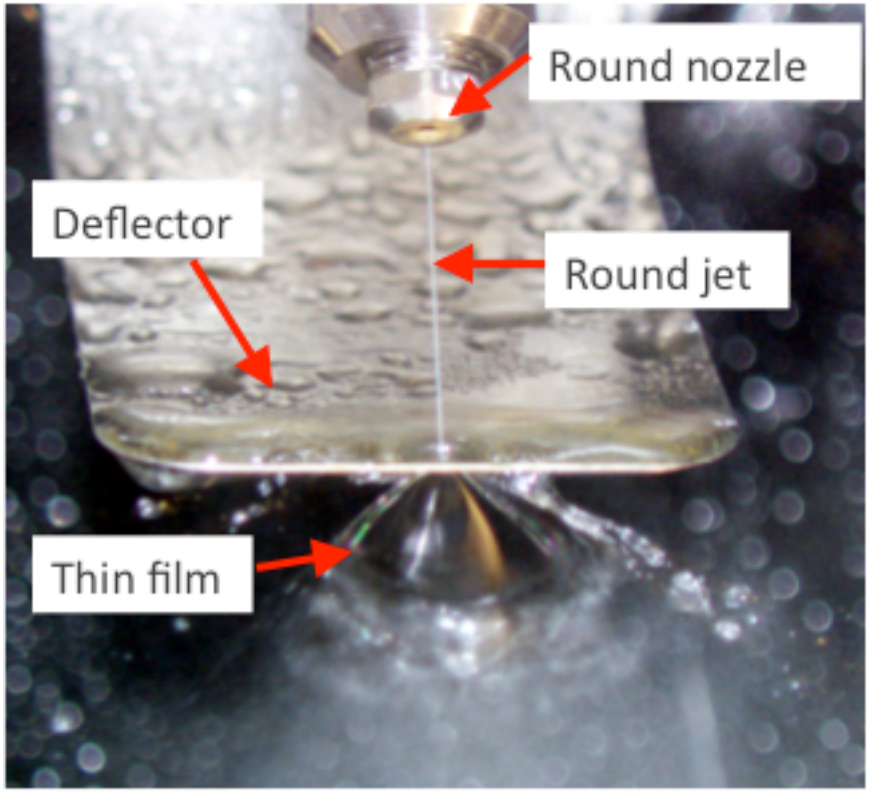
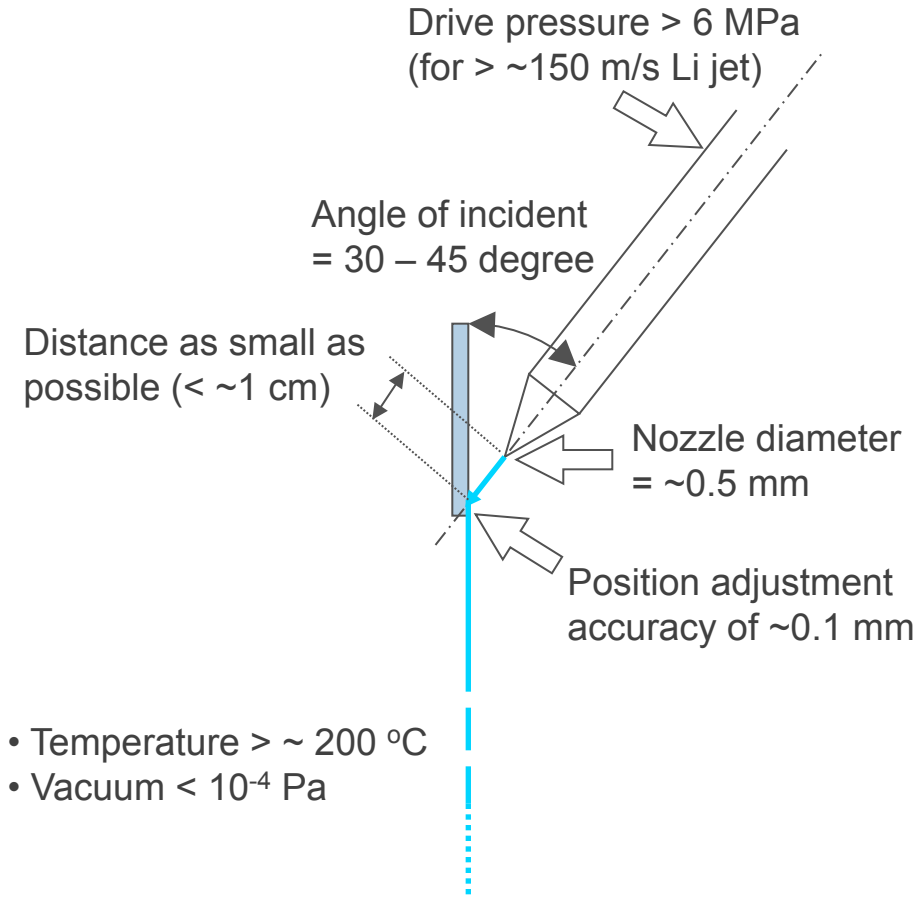


Demonstrate film in lithium

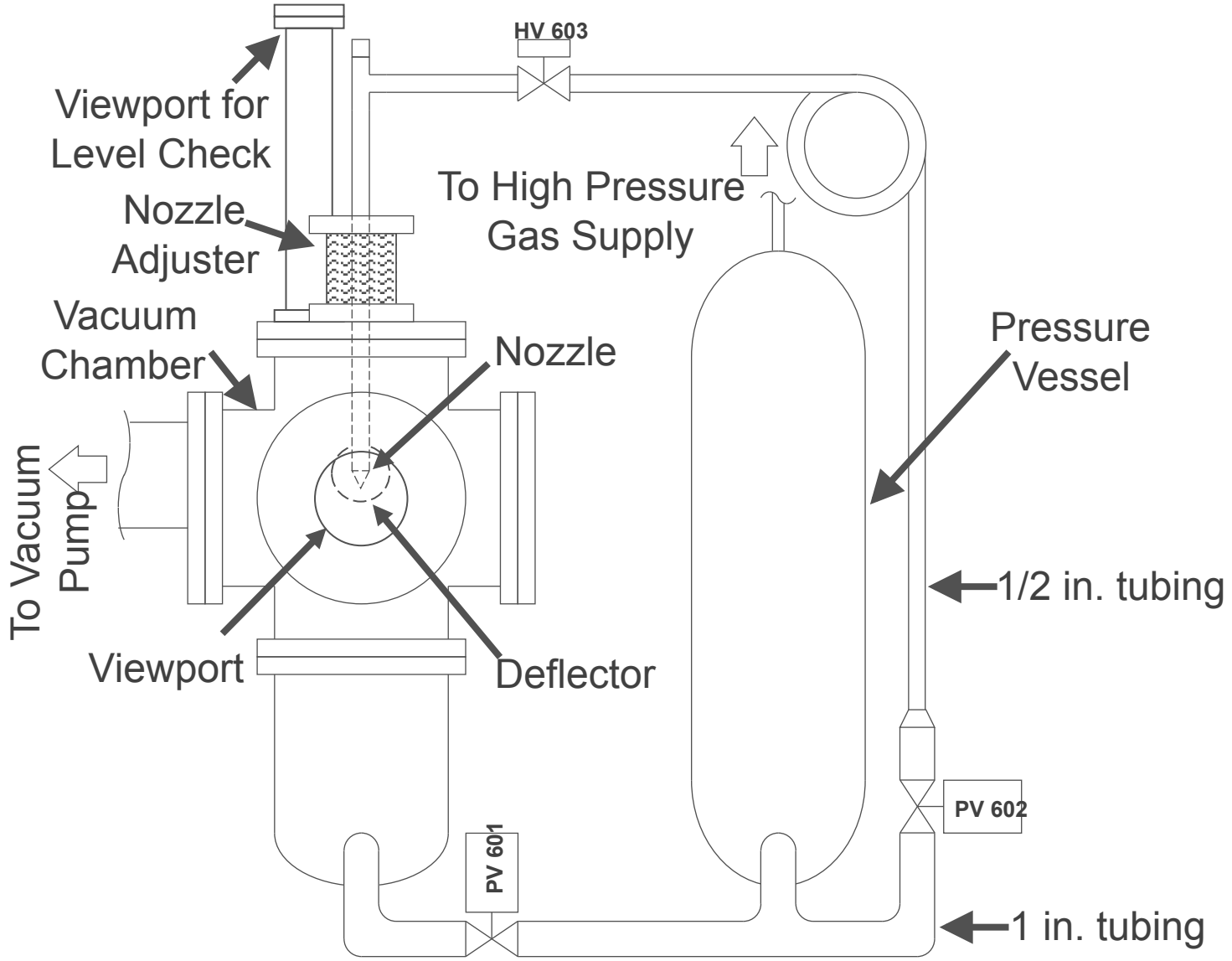
Thin film formation scheme & parameters

- Critical design parameters
  - Determined based on these 1st and 2nd phase experiments.

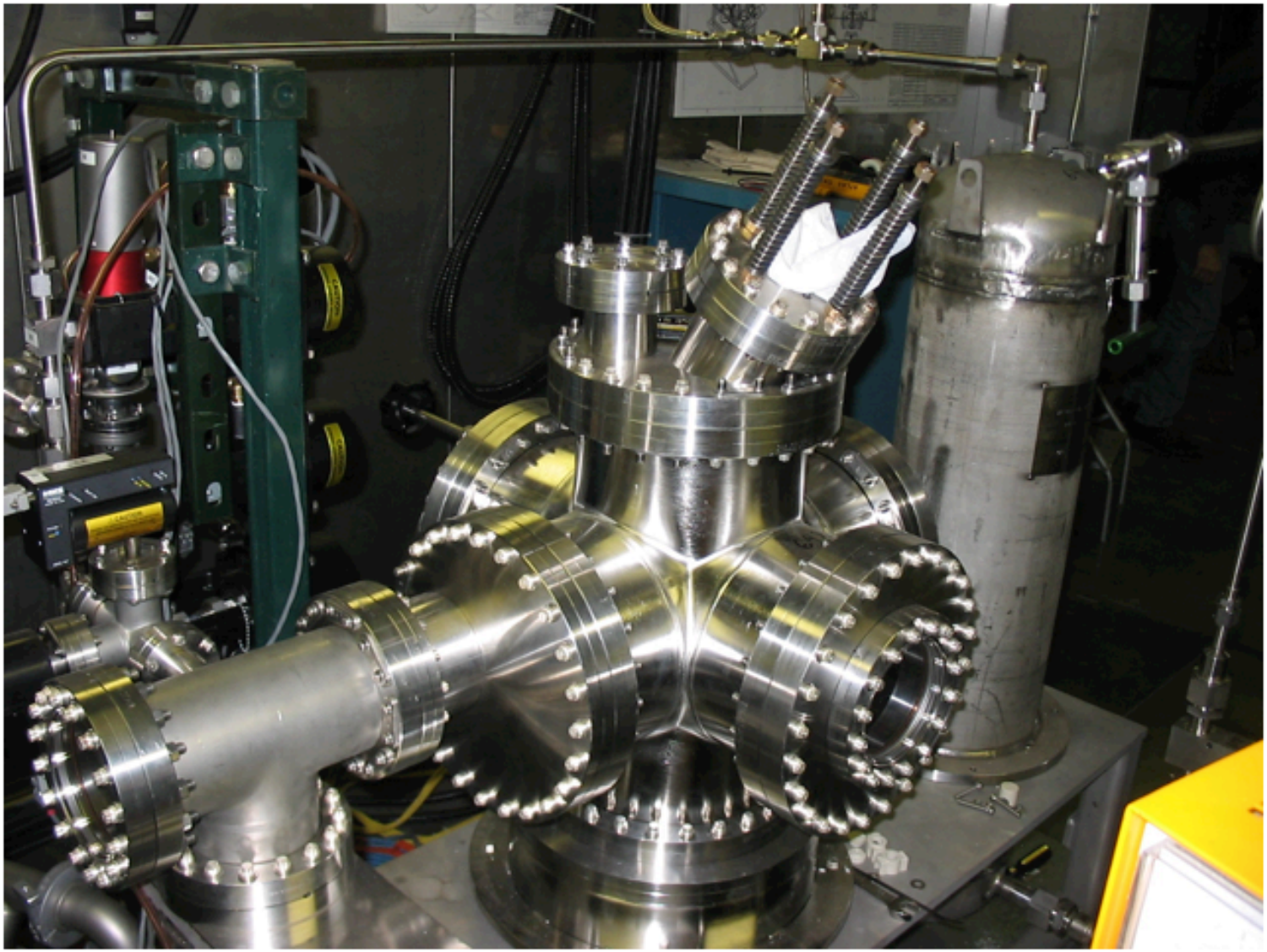




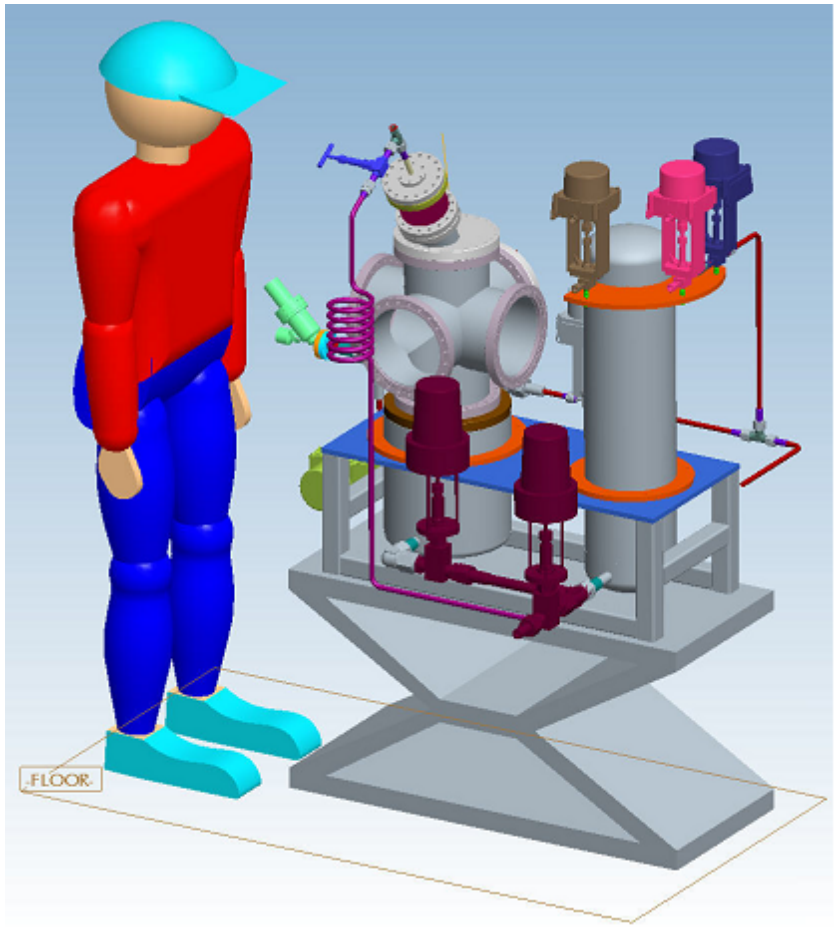
Schematic of Lithium System

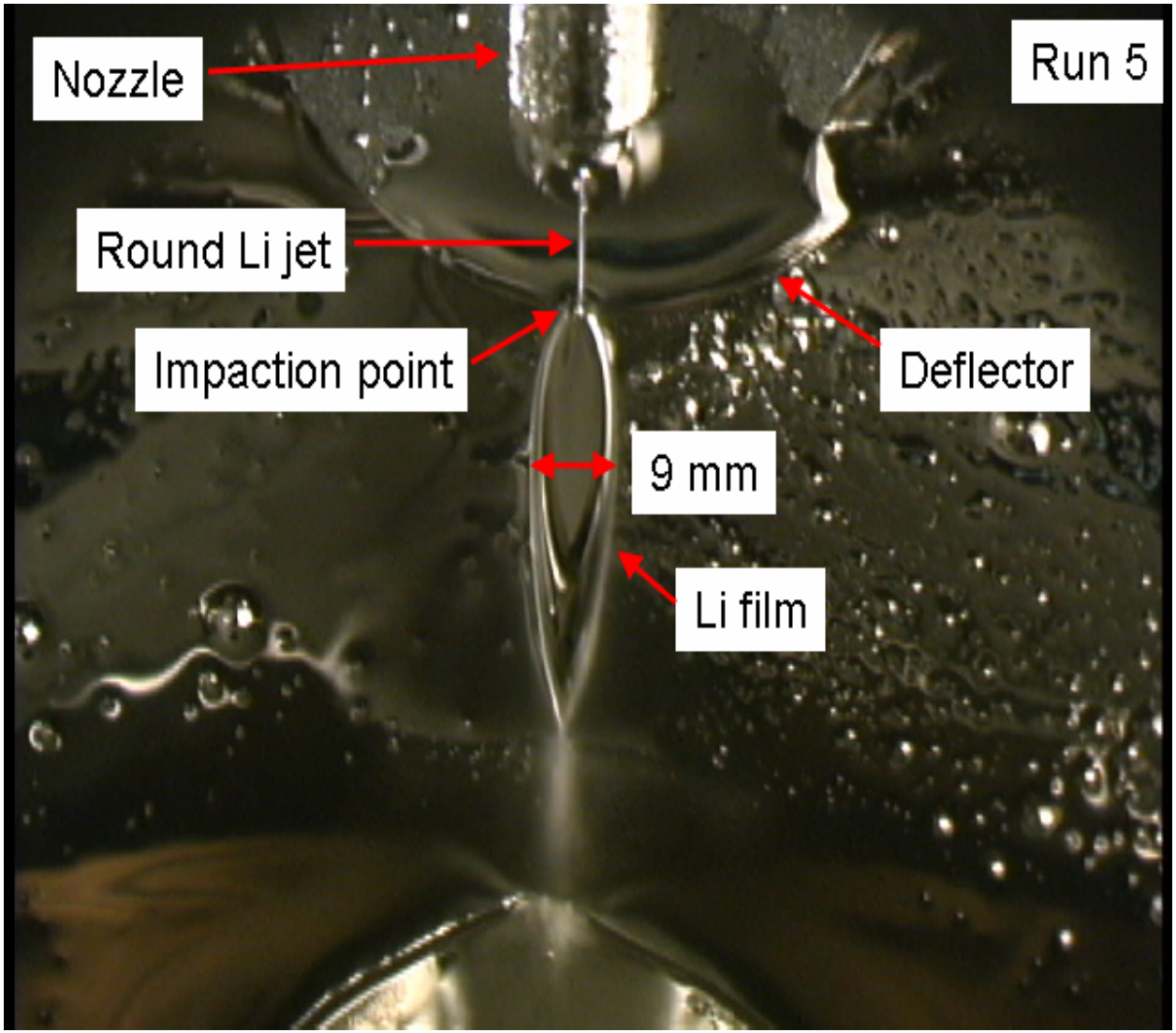


Old Li Stripper System

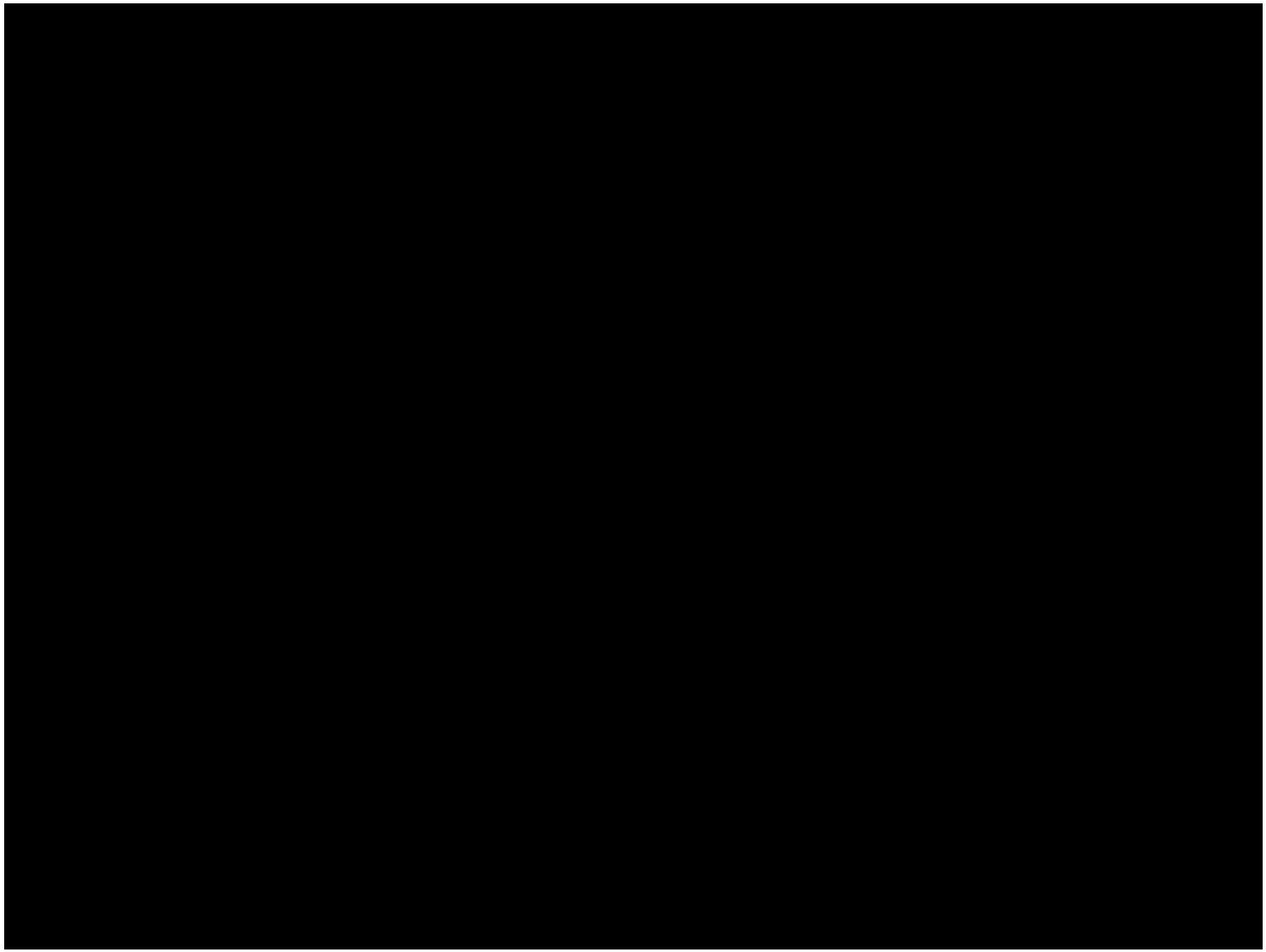


Approximate size of lithium stripper system



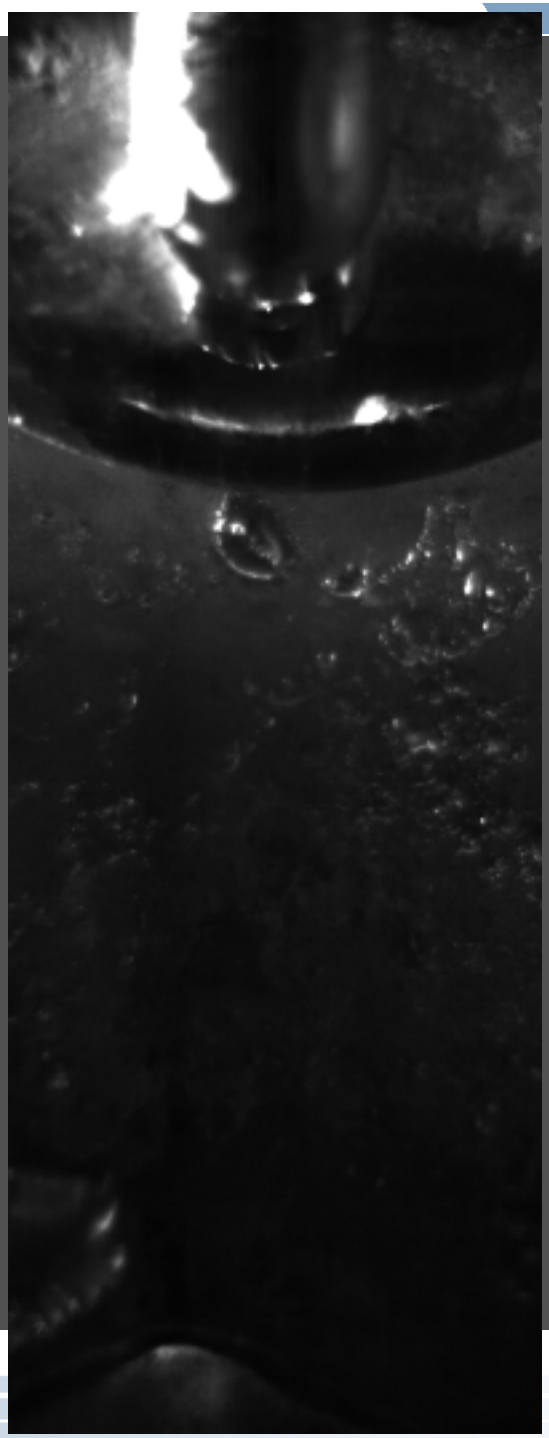


liquid lithium thin film

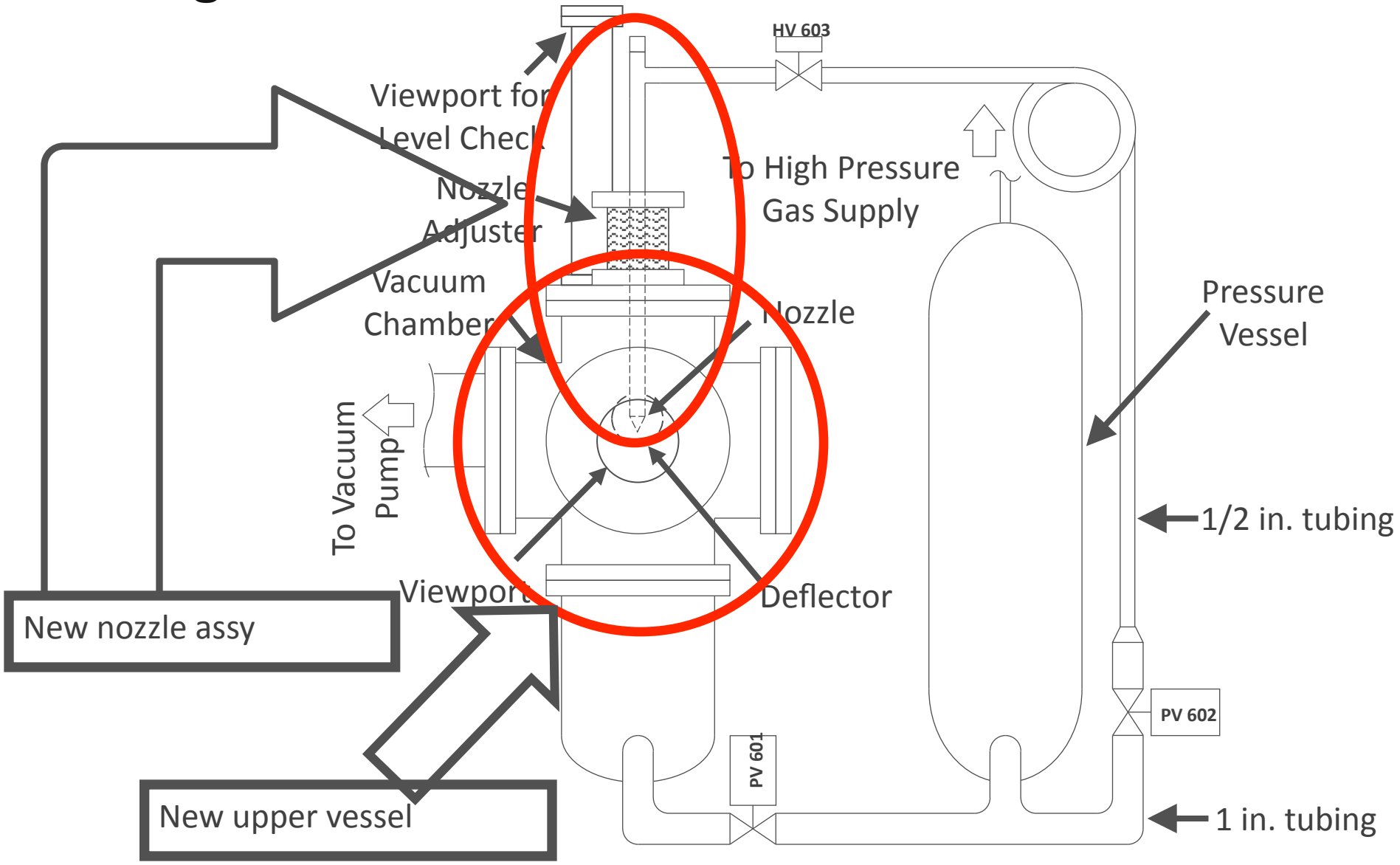


liquid lithium thin film

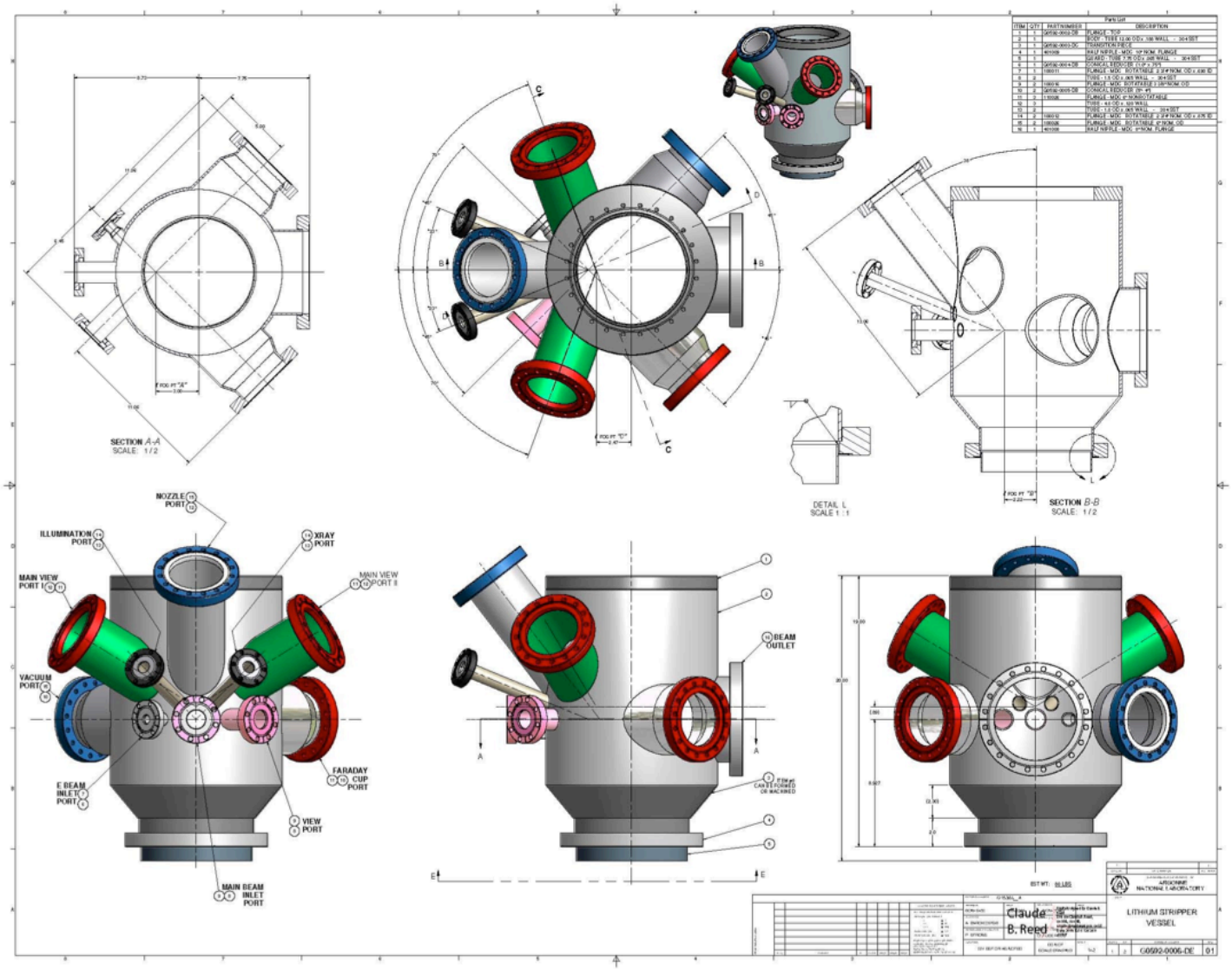
Record rate = 6,300 fps
Playback rate = 29.97 fps
Drive pressure = 2.8 MPa
Nozzle ϕ= 0.5 mm



Changes for FRIB

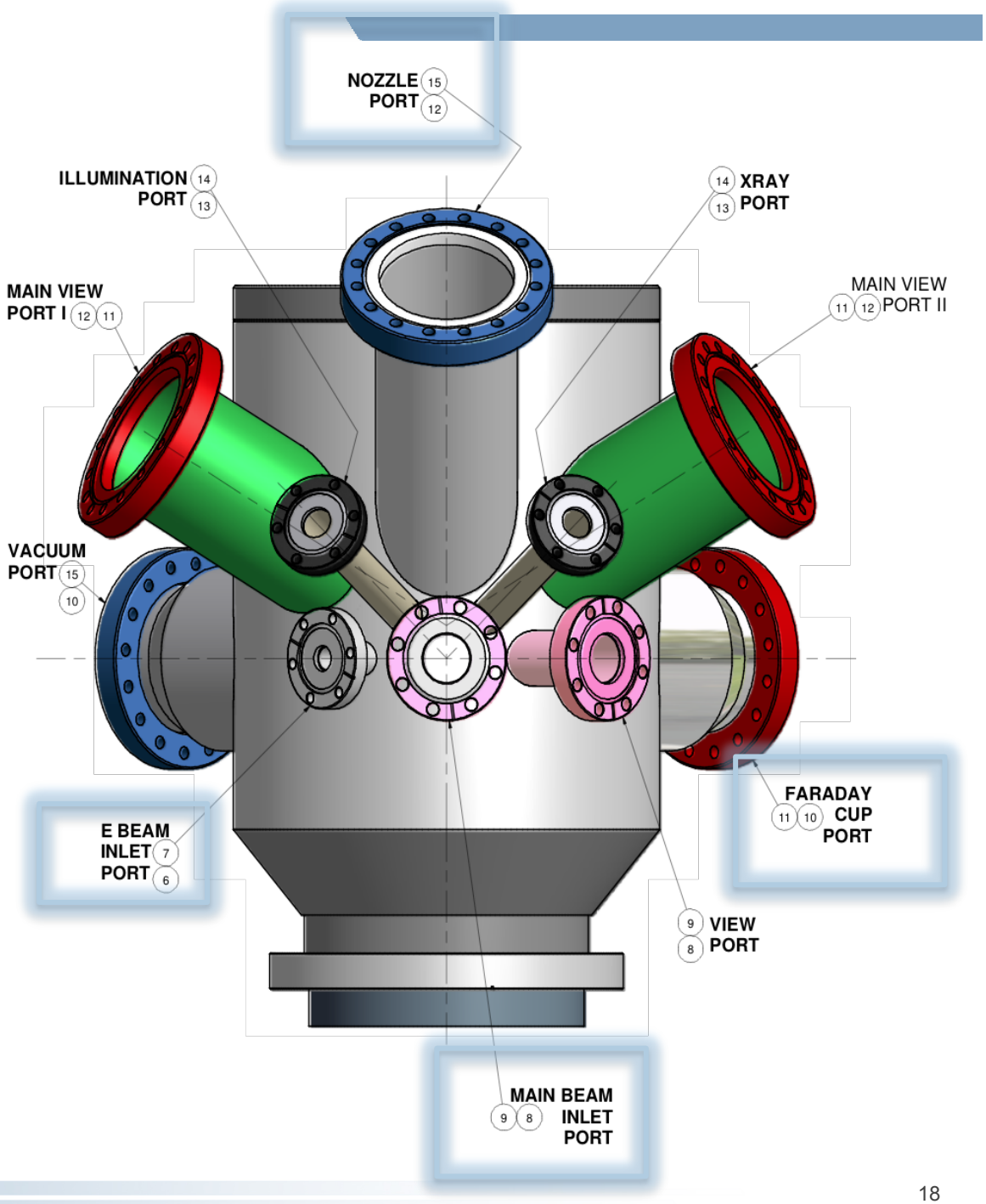


New Li Stripper Vessel



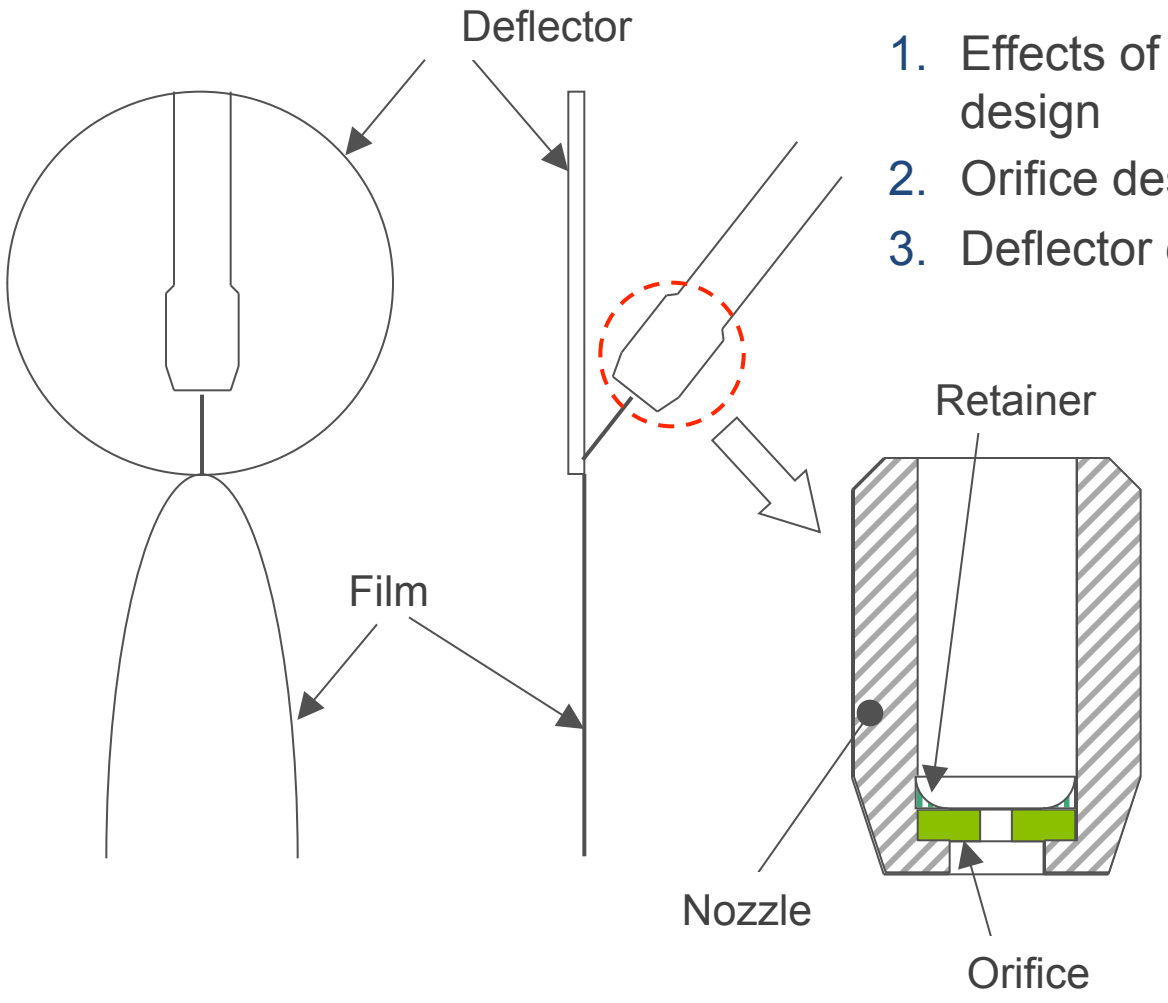
New Upper Vessel

- Upper vessel provides many ports to study and diagnose the liquid film
- View ports for visual observation

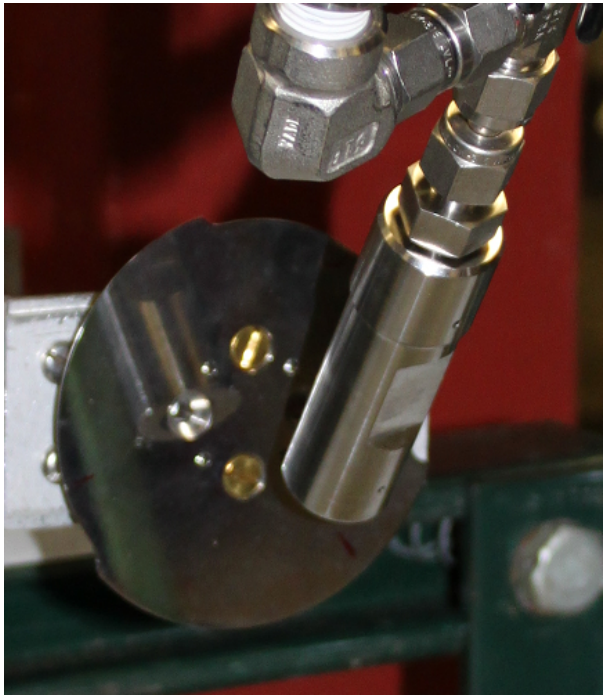


Film formation issues

- 3 fundamental issues

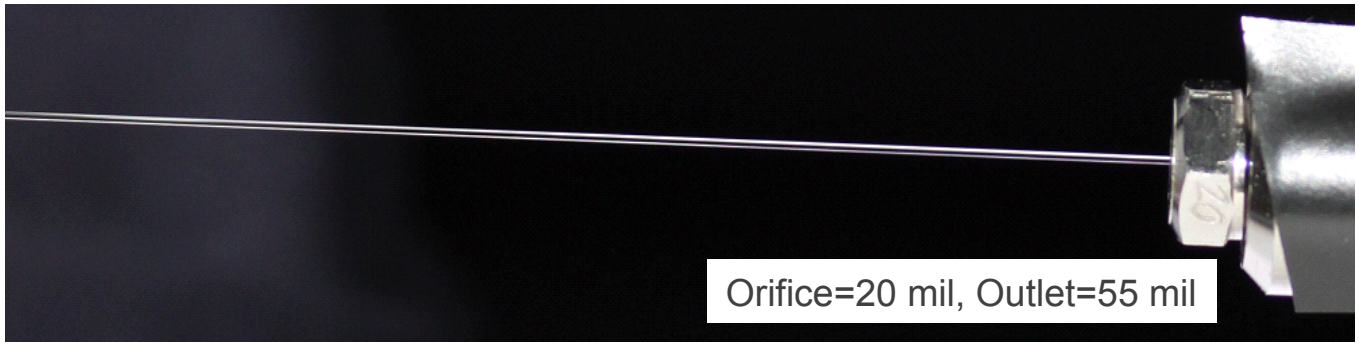


1. Effects of nozzle inlet and outlet design
2. Orifice design, material, and finish
3. Deflector design and finish

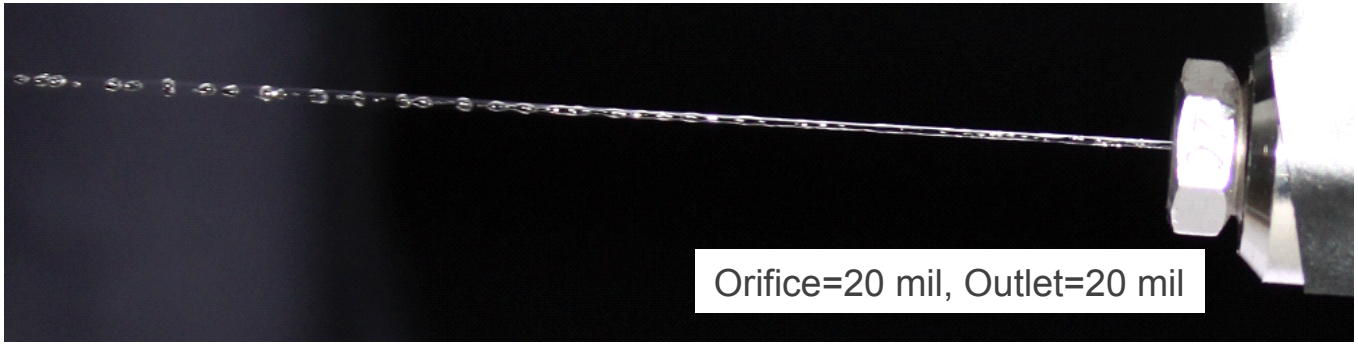


Nozzle development

- Effects of nozzle inlet and outlet design



20 mil Al2O3
File:100-265



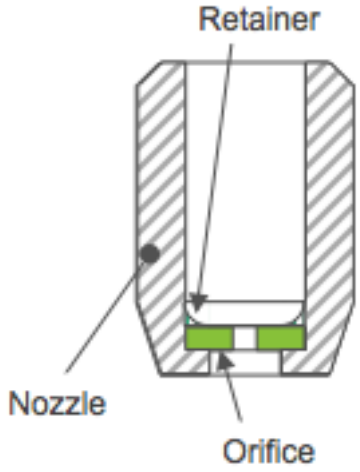
20 mil SS
File:100-275

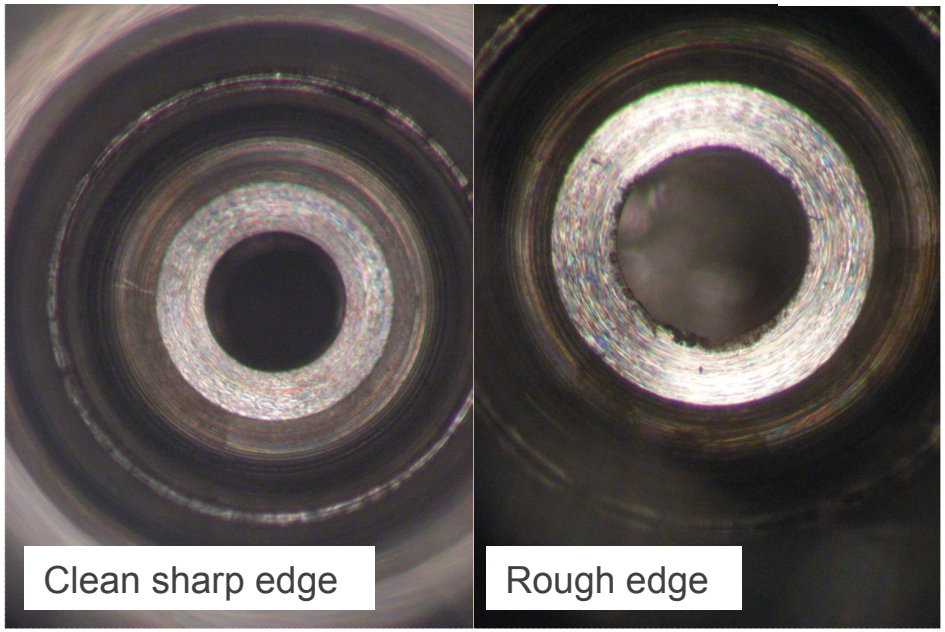
10 psi

Nozzle development

- Orifice design, material, and finish

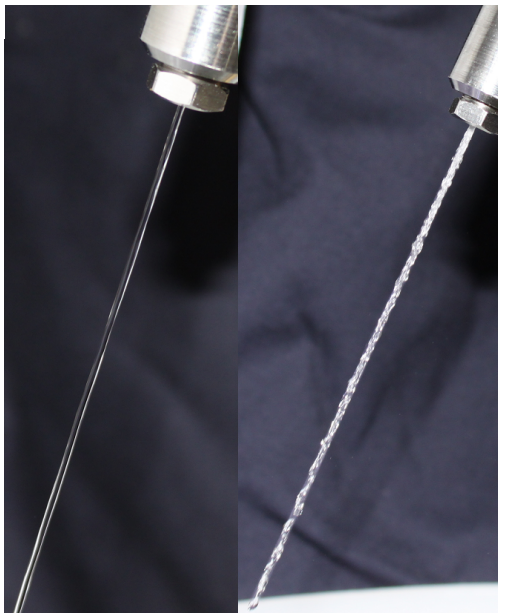
1. Well defined orifice
2. Stainless steel, orifice
3. Three-piece design





40-40 mil SS X

40-40 mil SS (2)

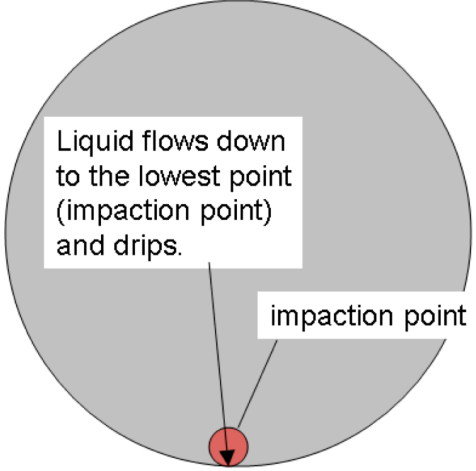


20 psi

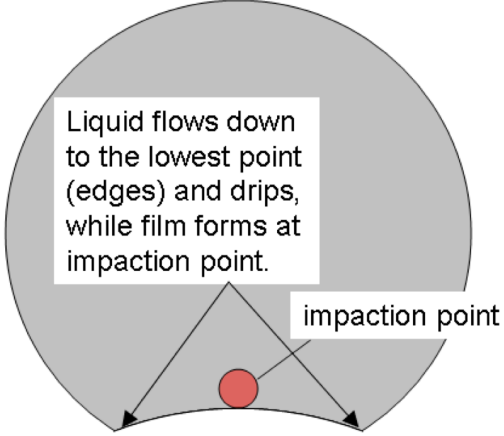
40-40 mil SS X
File:100-452

40-40 mil SS (2)
File:100-528

Deflector Issues



Old deflector



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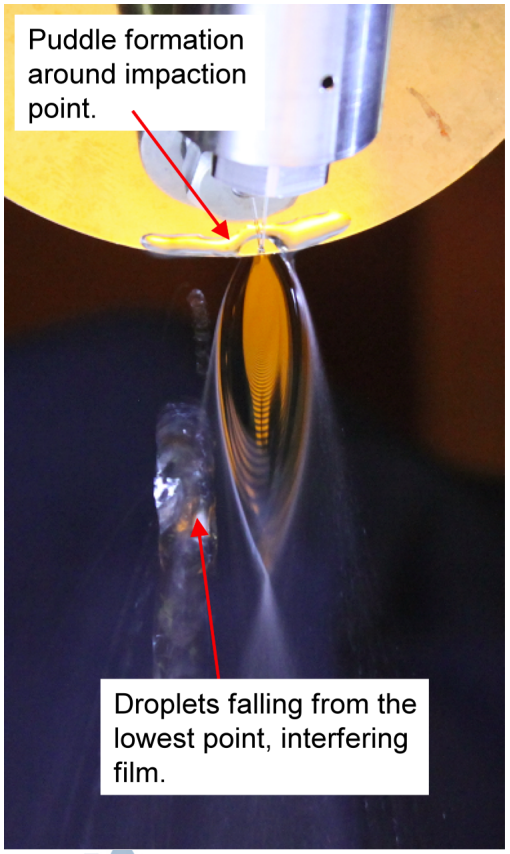
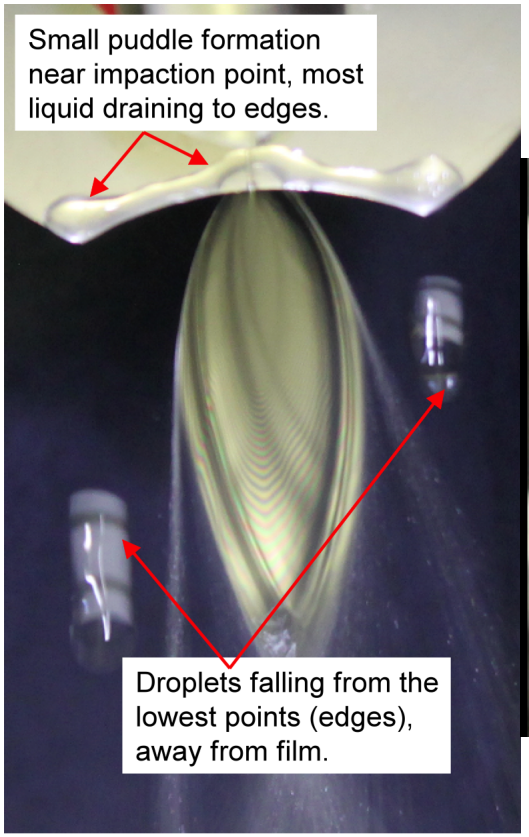
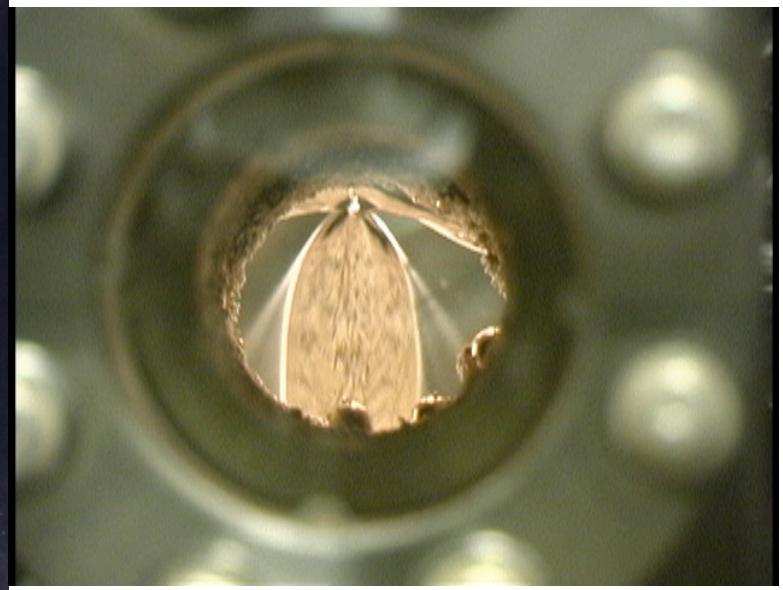
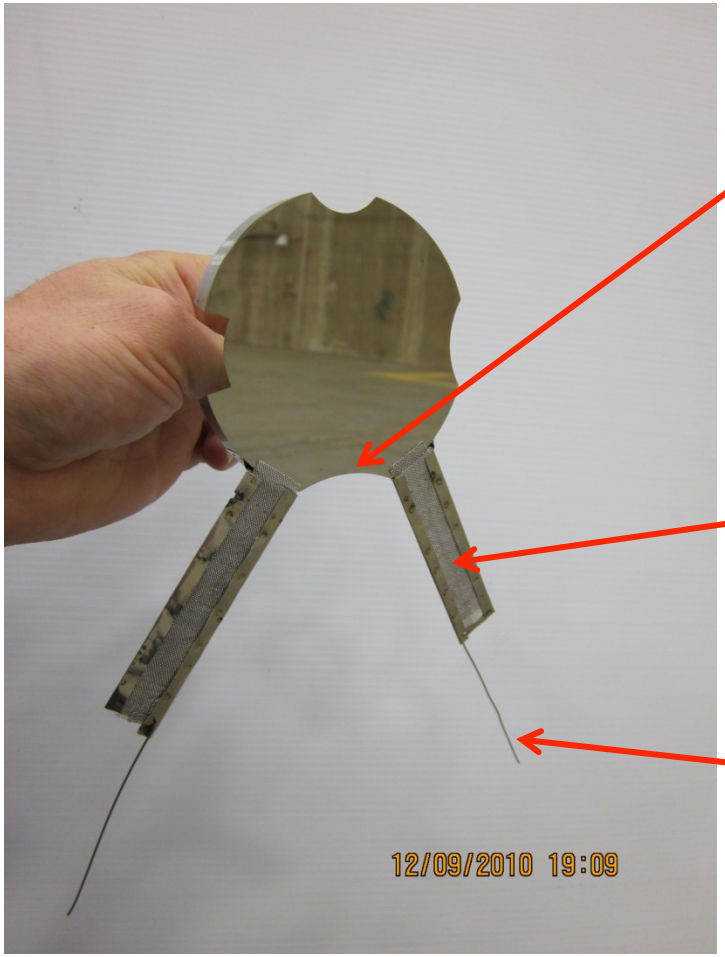






Li Film

4-Profile Deflector With Wicks



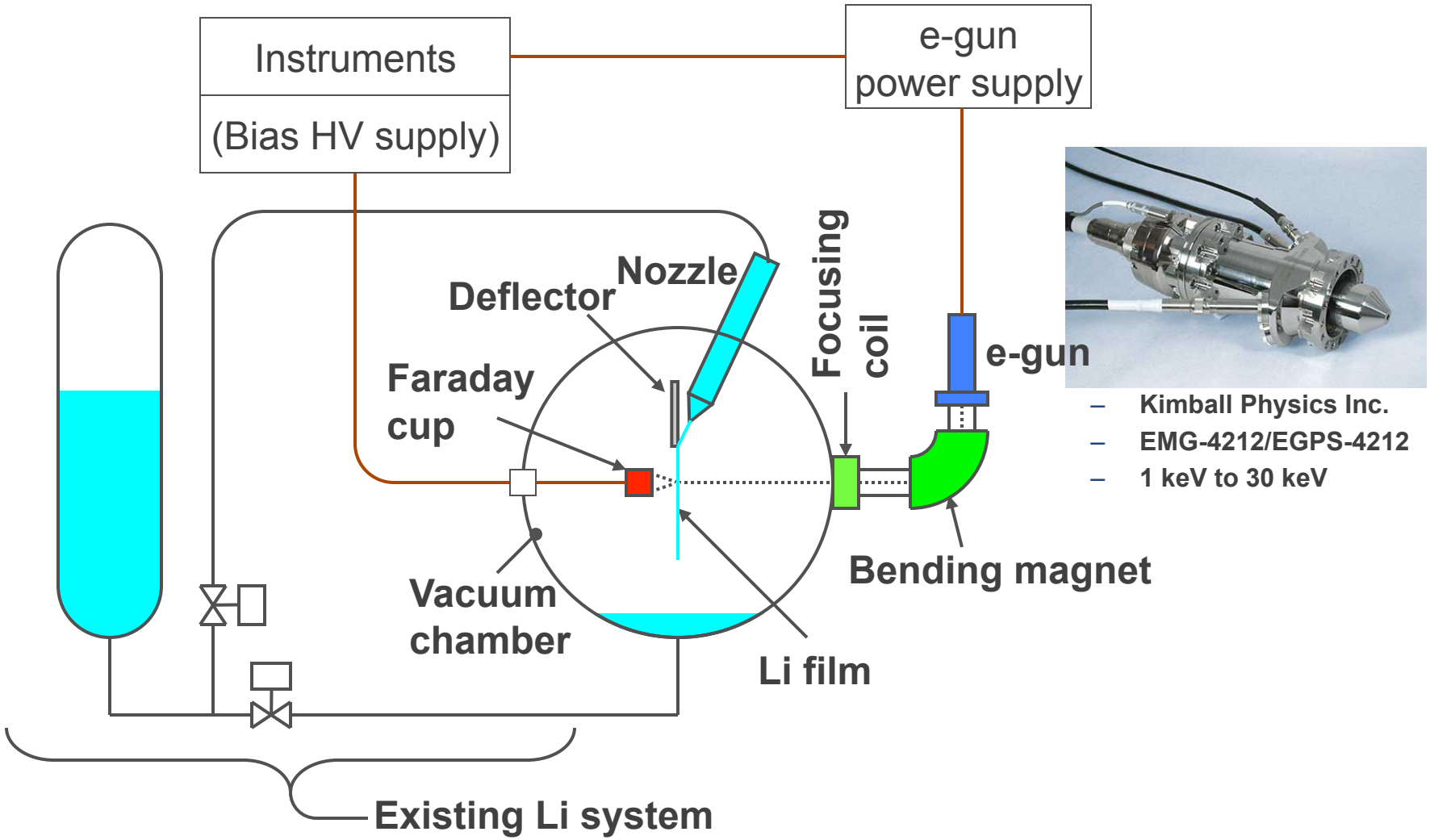
1 µ diamond polish on face and both sides of knife edge

Stainless steel mesh wicking to "pull" Li from deflector face and reduce puddling

Stainless steel wire to guide Li droplets down and away from film

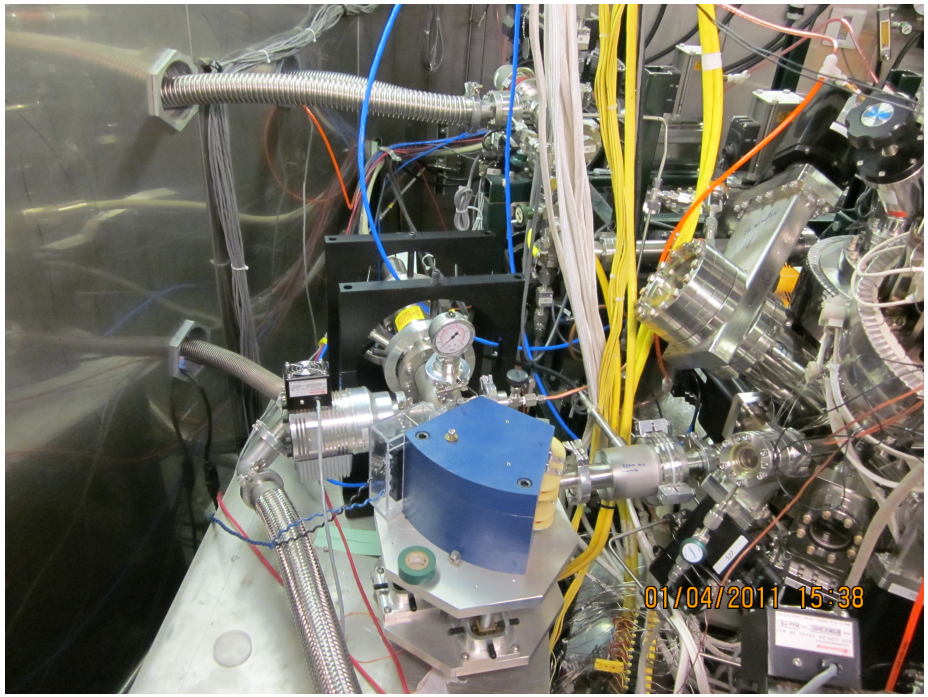
EMS system and operation

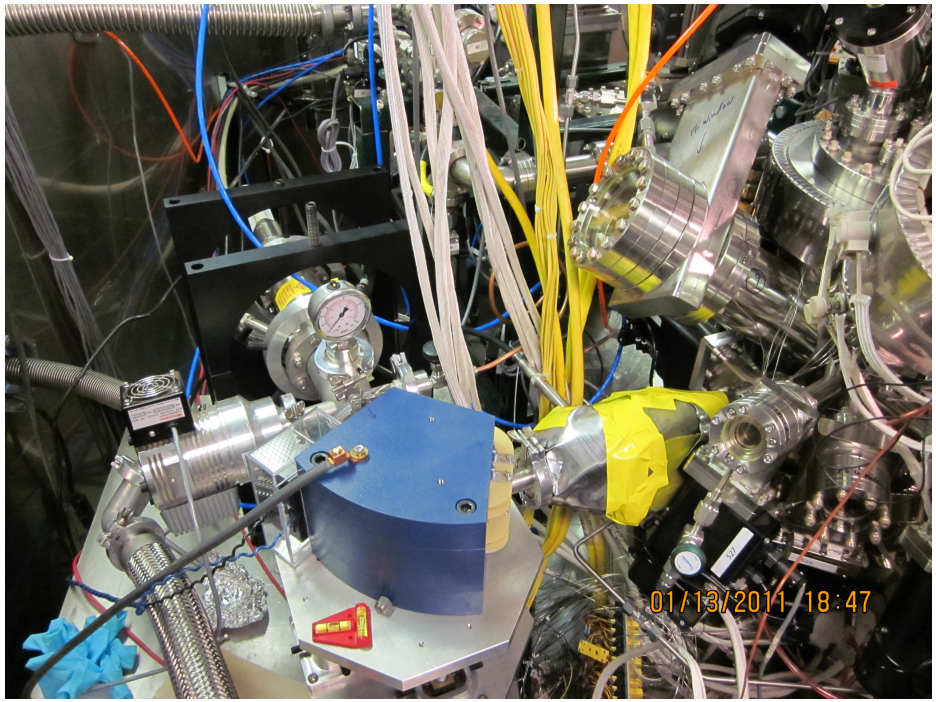
- System layout



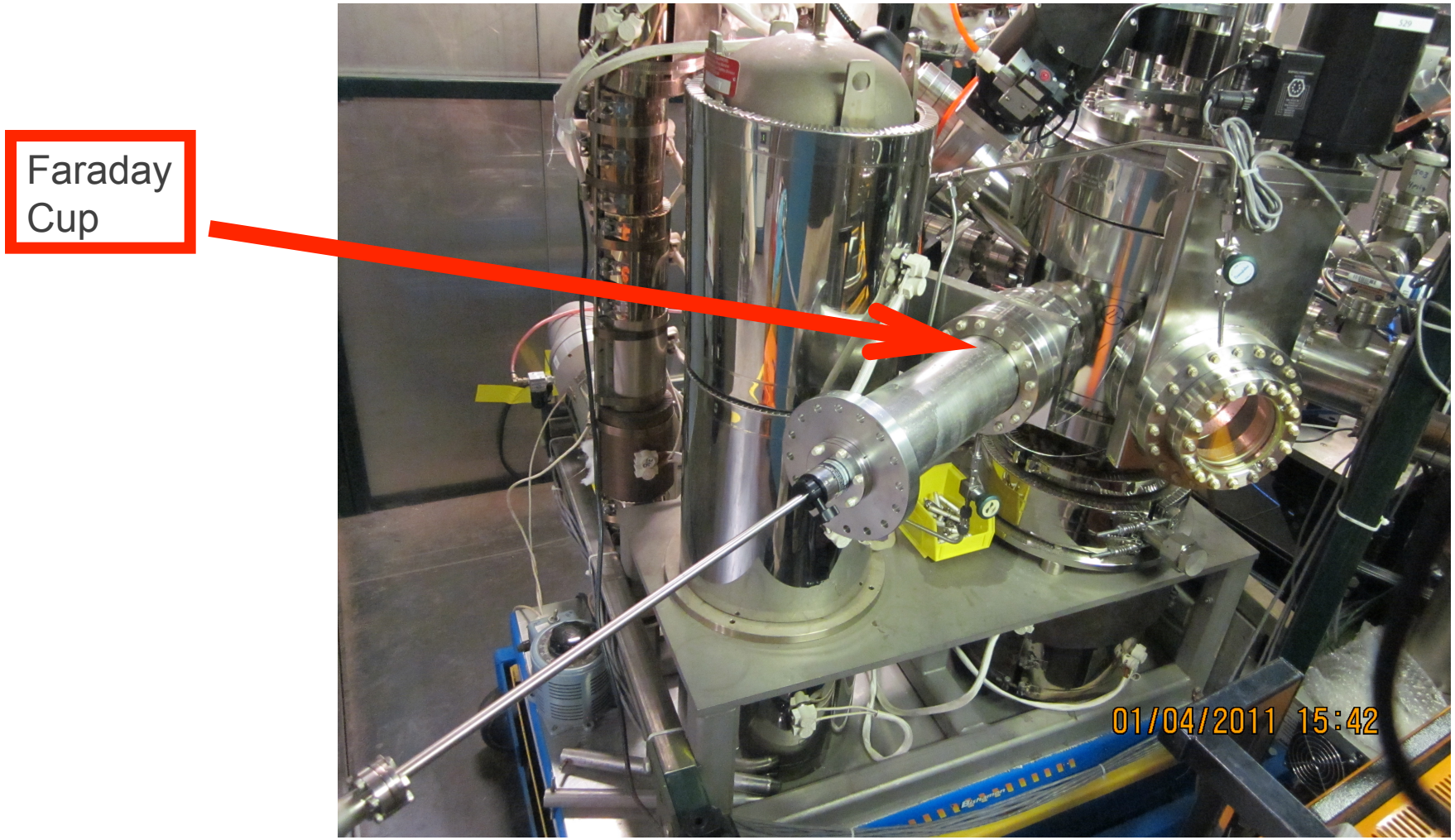
- Kimball Physics Inc.
- EMG-4212/EGPS-4212
- 1 keV to 30 keV

E-GUN SYSTEM INSTALLED ON LI VESSEL

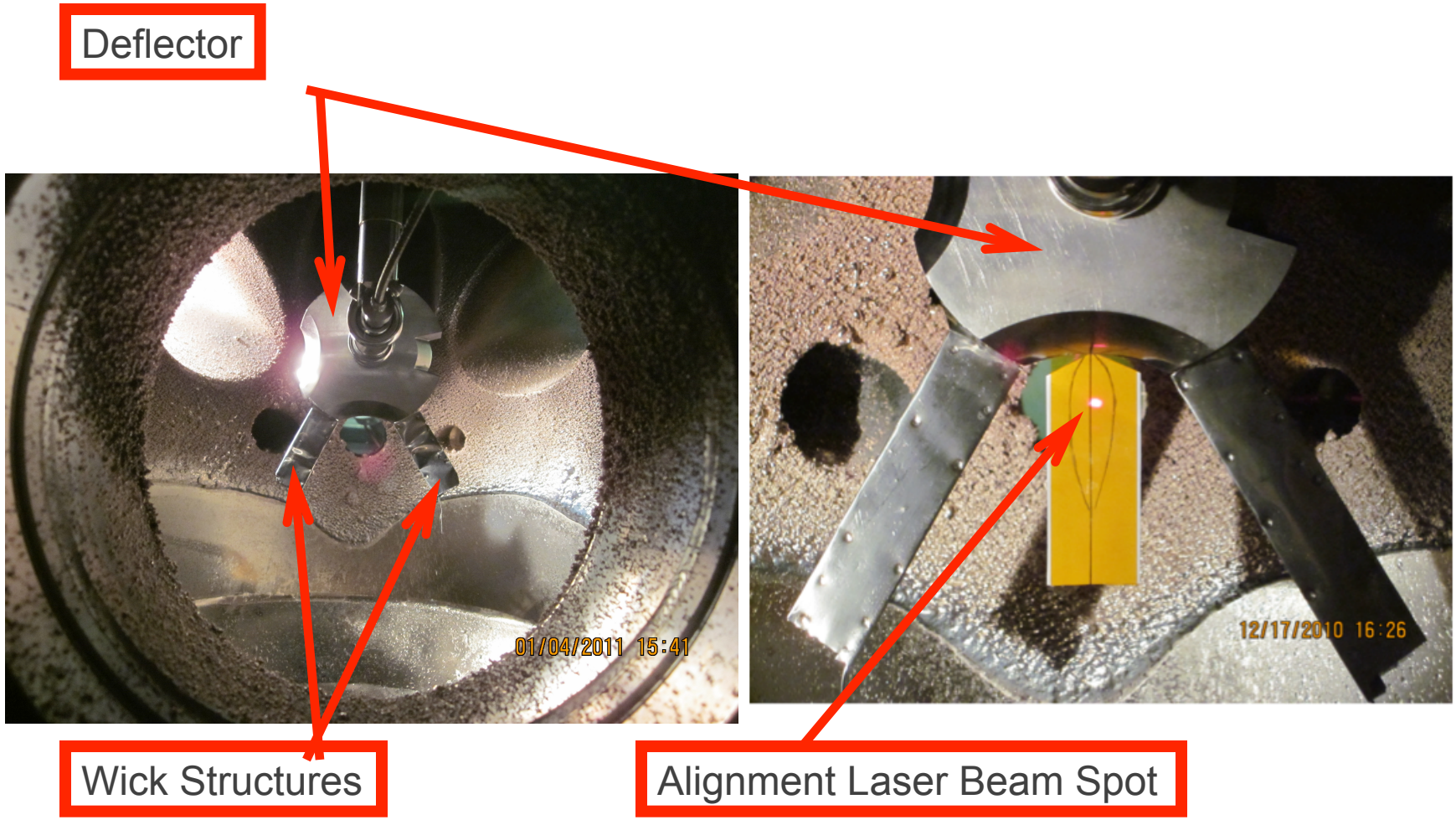




FARADAY CUP



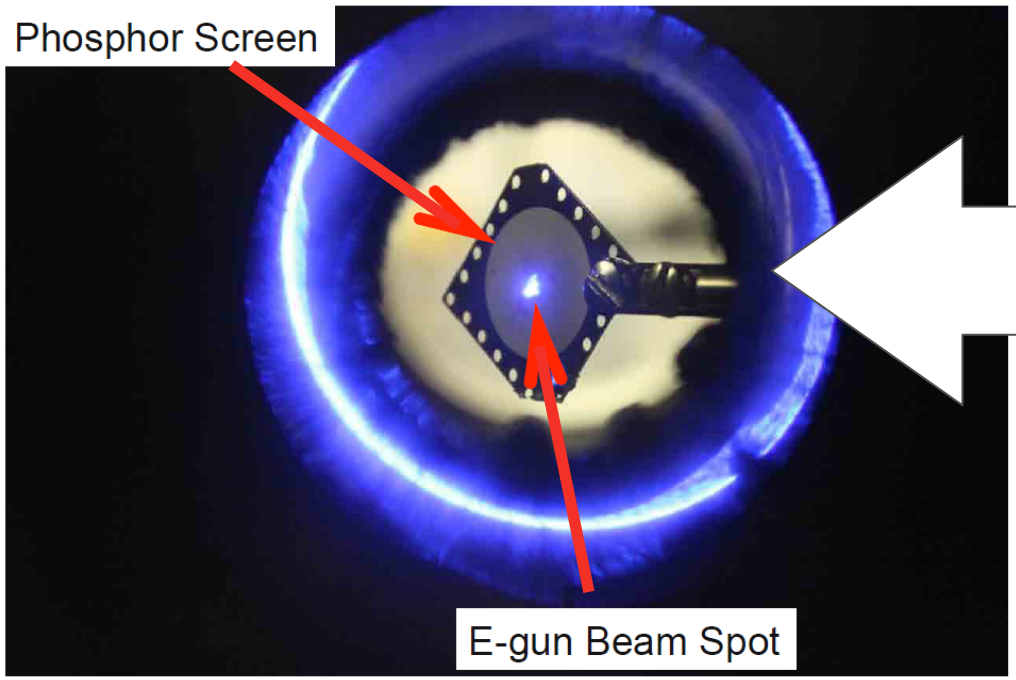
CUSTOM LASER ALIGNMENT DEVICE HELPS POSITION DEFLECTOR

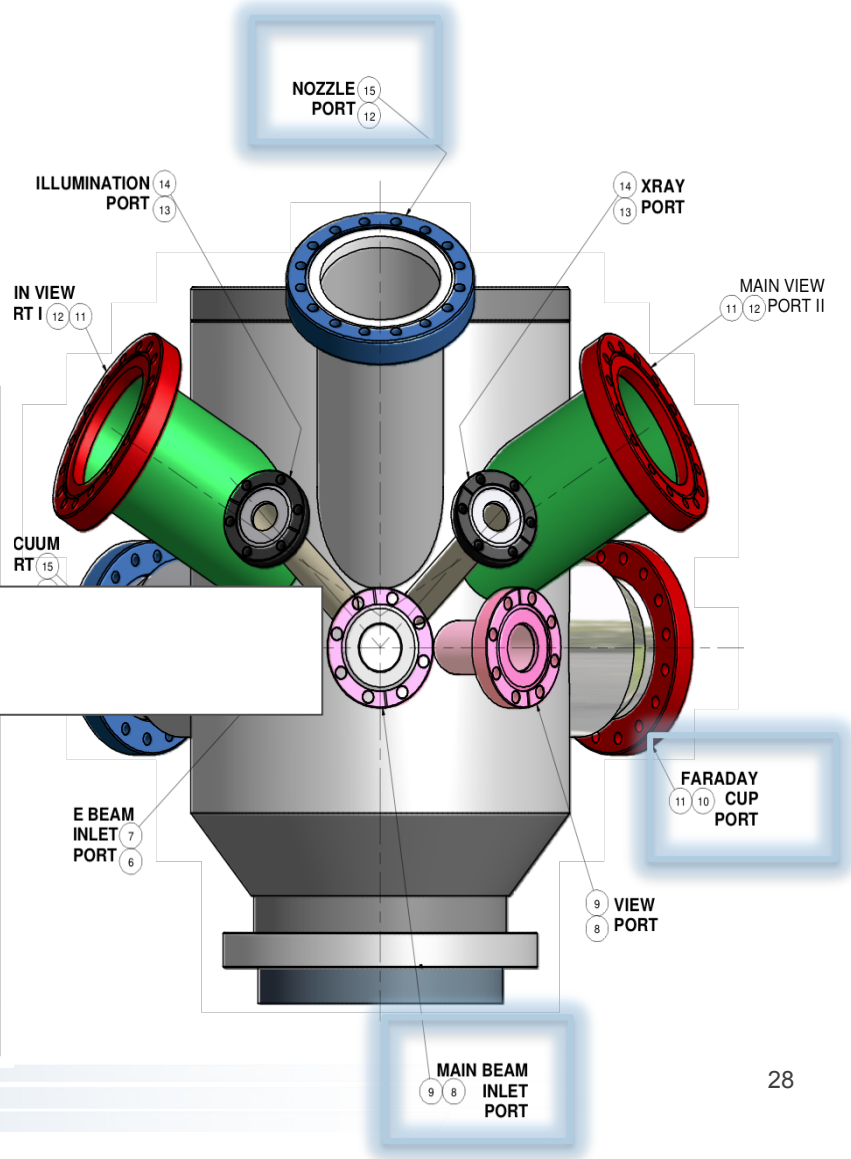


Electron Beam Alignment

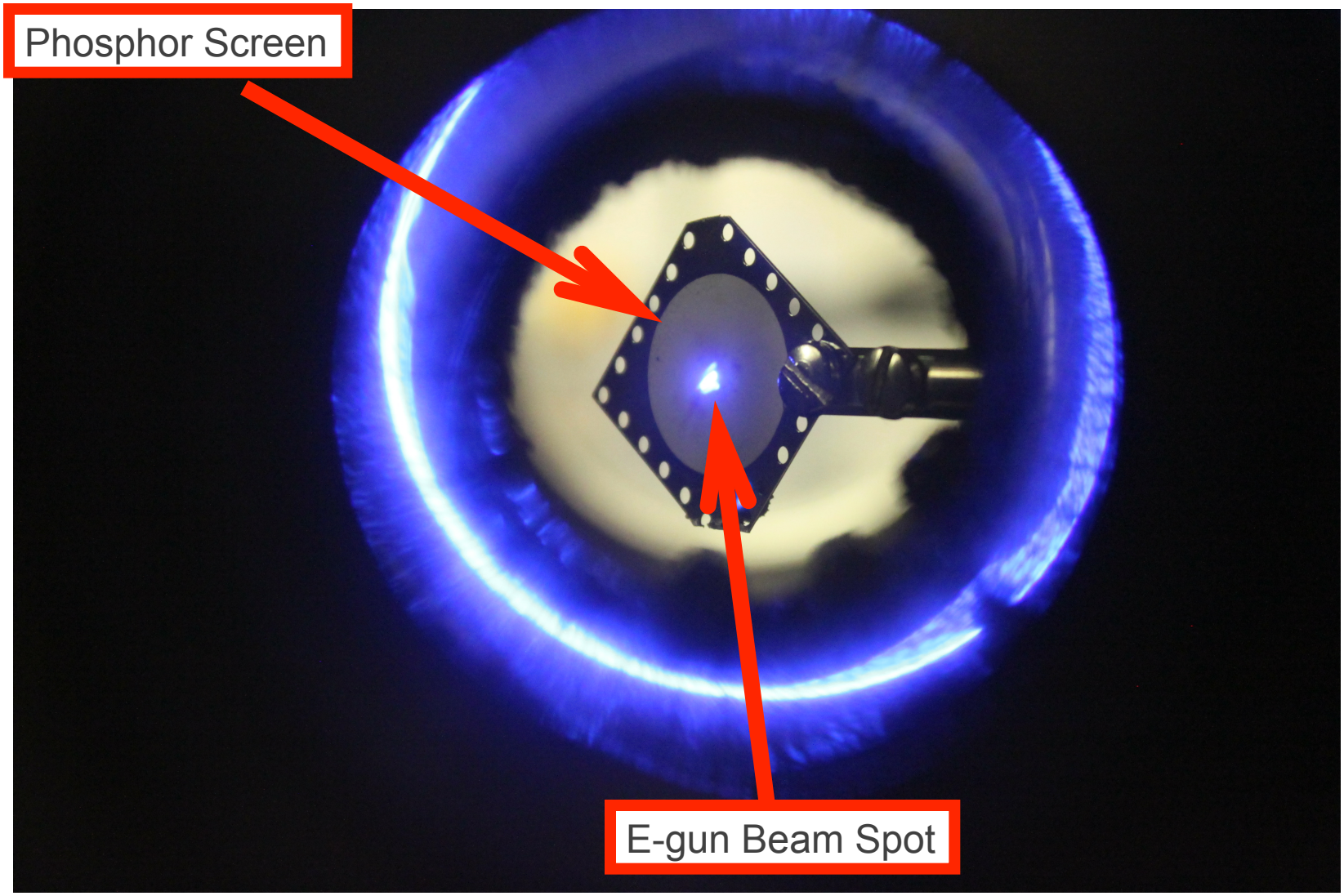
- The electron beam gun is aligned at the position of the lithium film with the temporary installation of a phosphor screen

E-BEAM ON PHOSPHOR SCREEN
(looking through ion beam port)

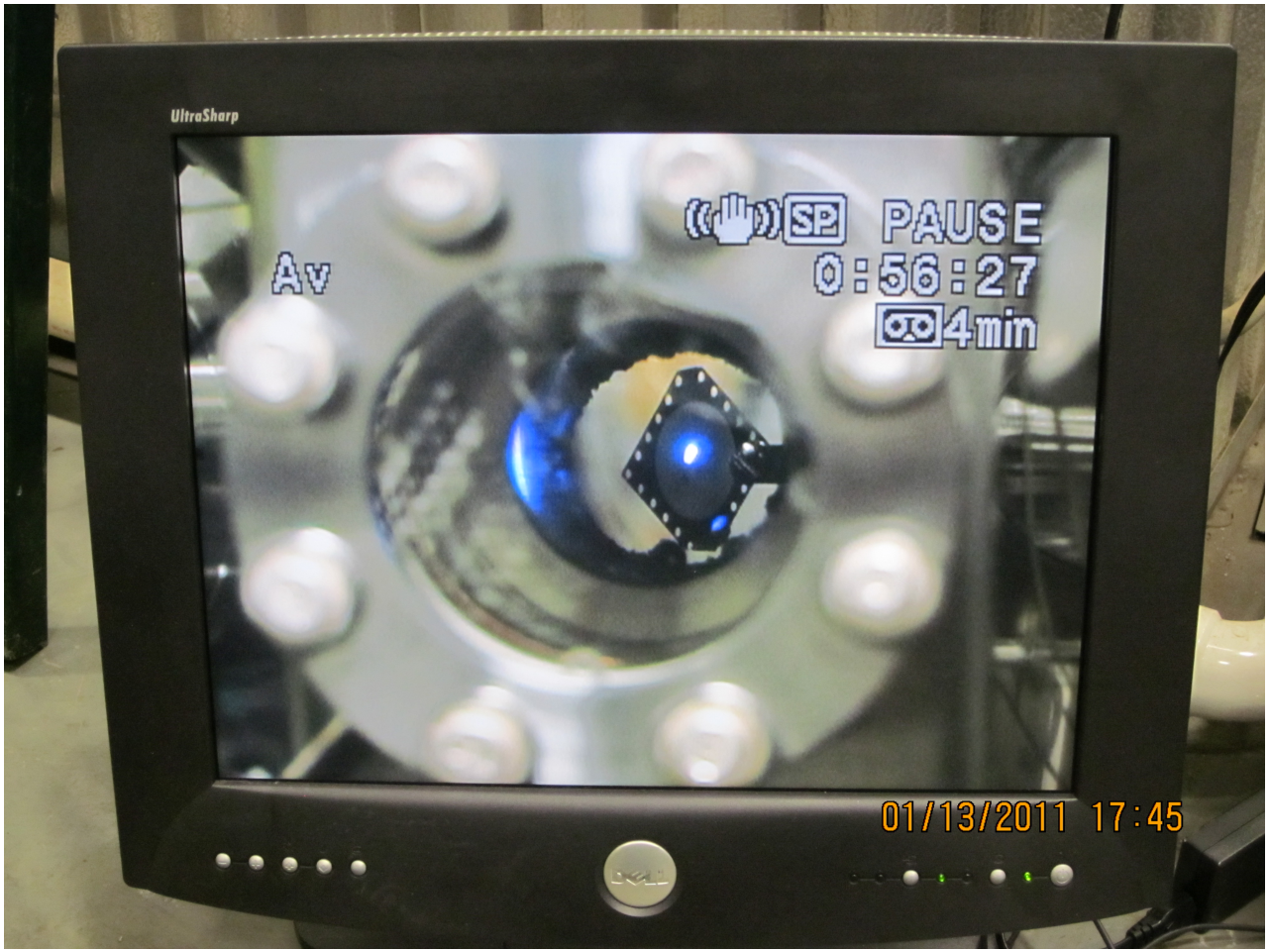




E-BEAM ON PHOSPHOR SCREEN (looking through ion beam port)



REAL TIME REMOTE S-VIDEO SCREEN IMAGES
4 MULTI-MEGAPIXEL DV CAMERAS



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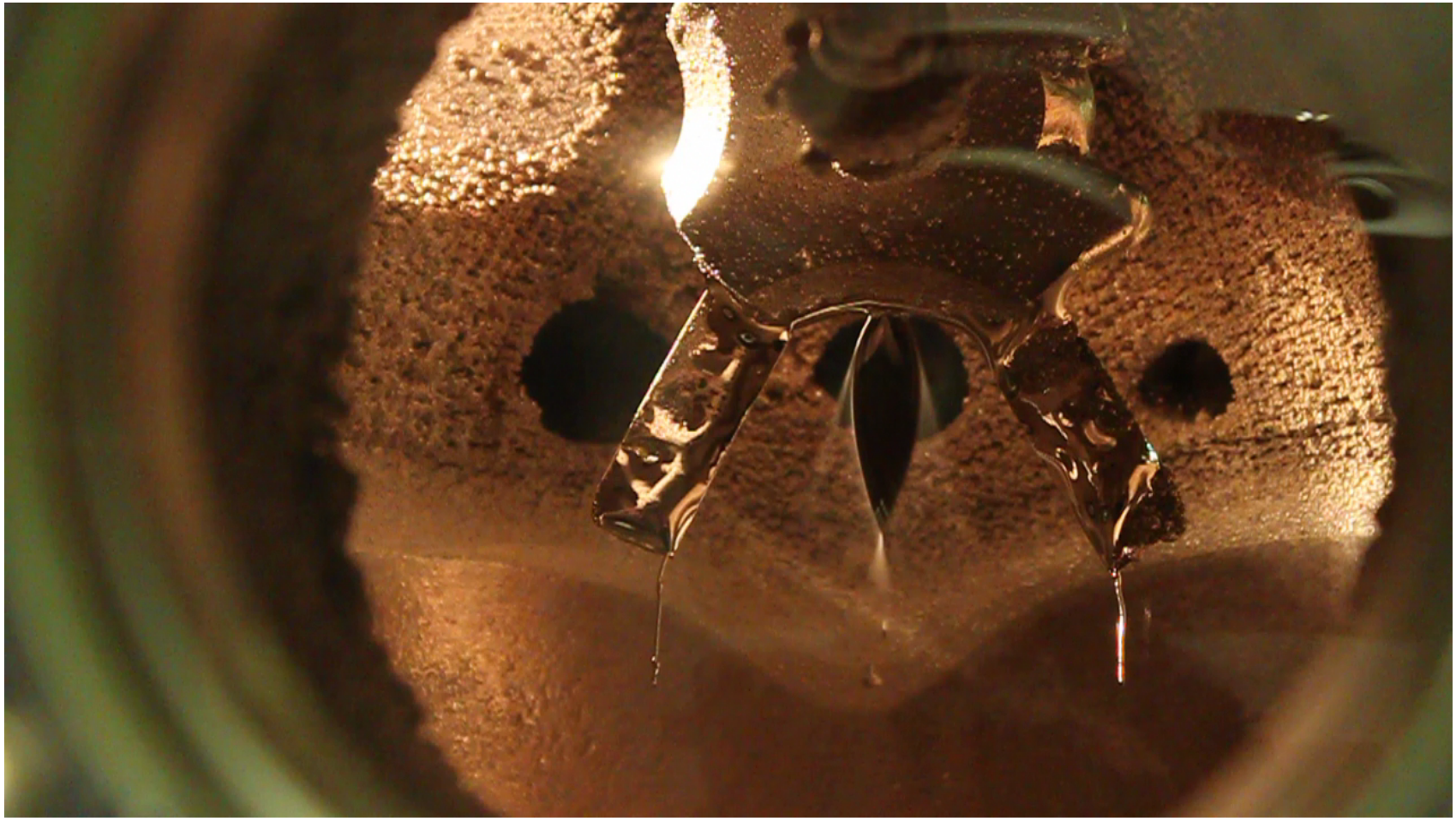
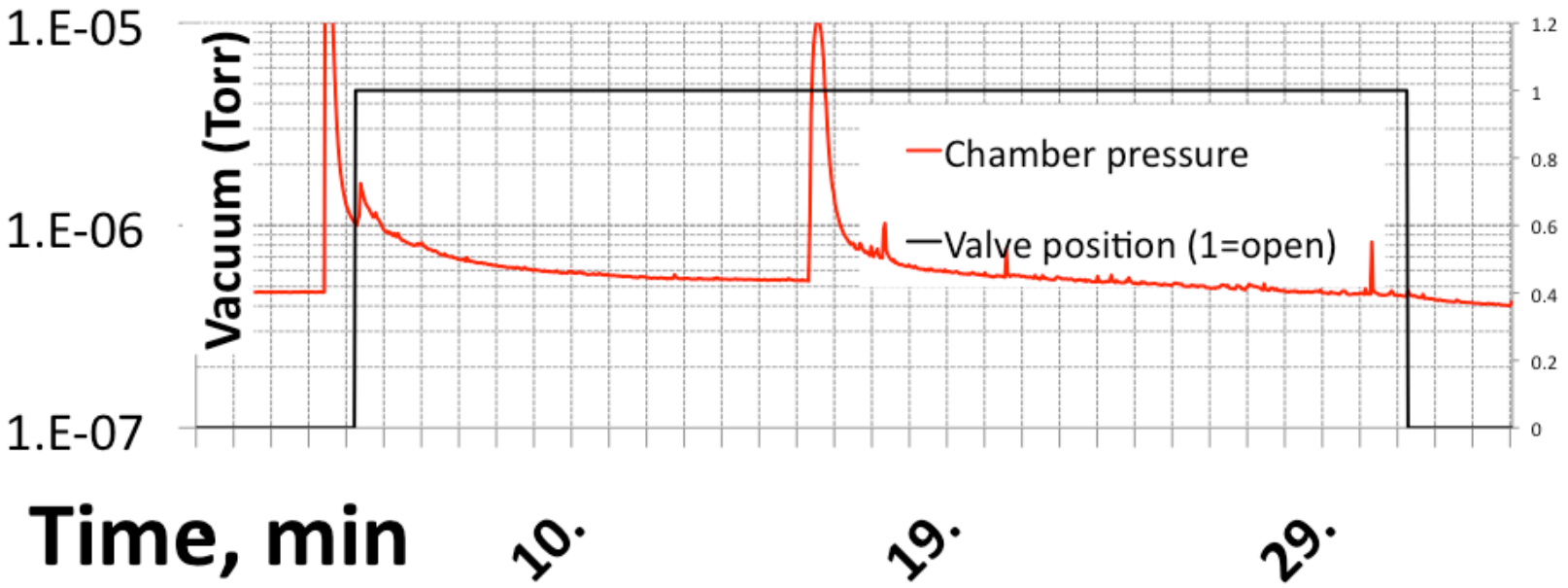
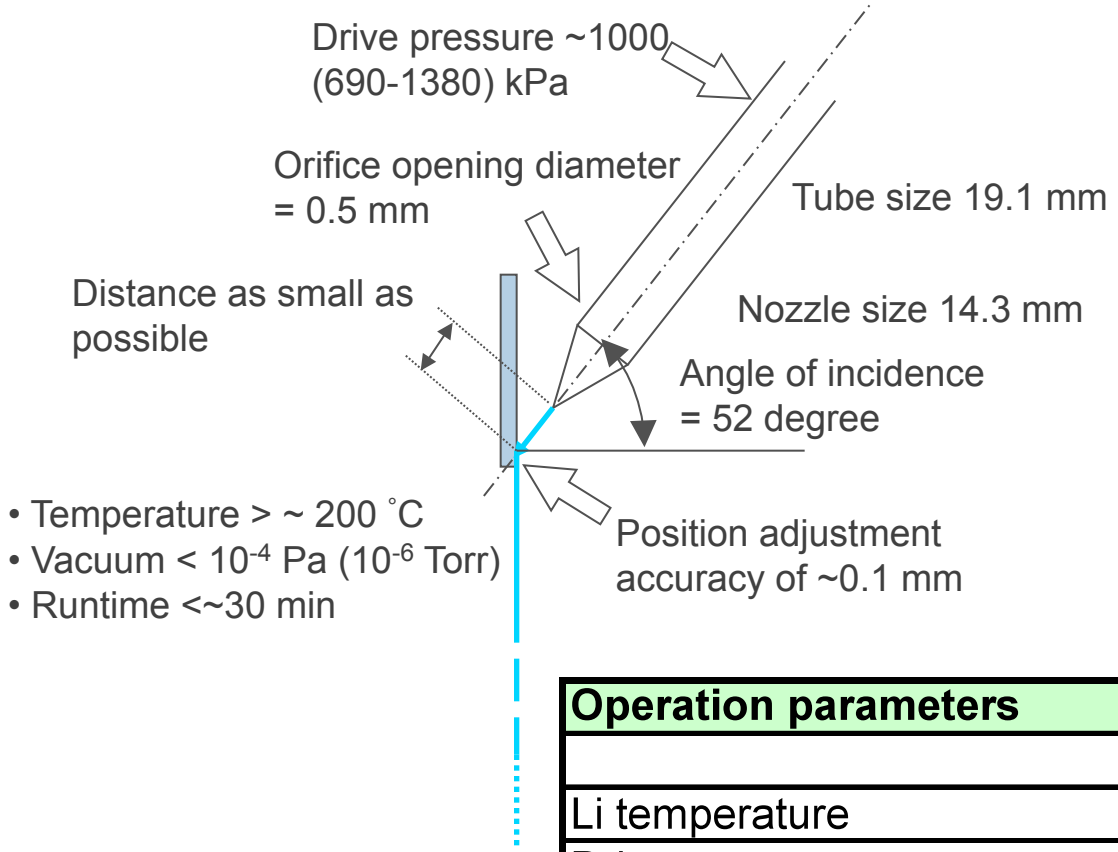


Stripper Chamber Vacuum Level



Operating conditions, experimental parameters

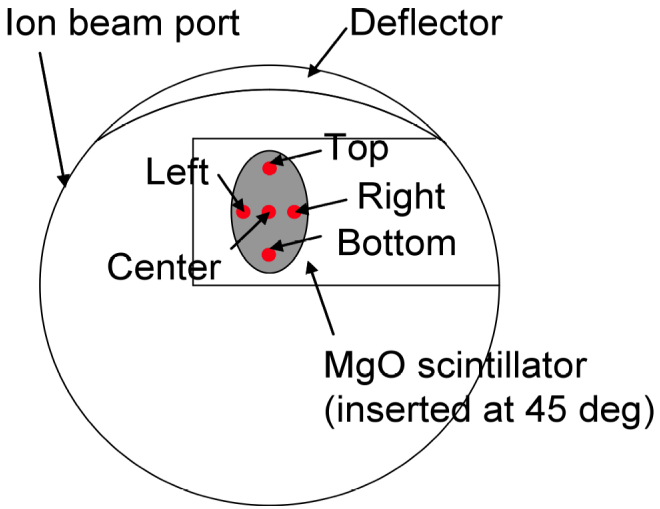


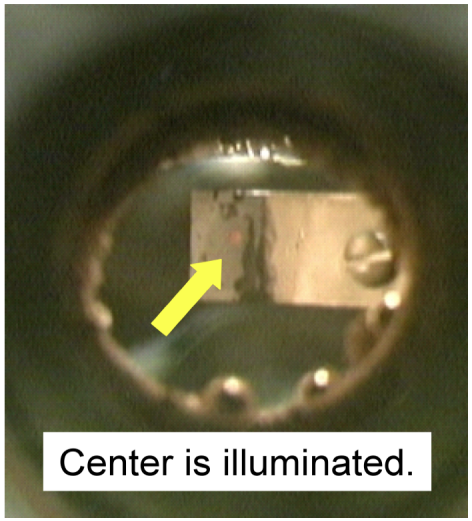
- Temperature > ~ 200 ˚C
- Vacuum < 10^{-4} Pa (10^{-6} Torr)
- Runtime <~30 min

Operation parameters	
Li temperature	220 °C
Drive pressure	550 - 1380 kPa
Estimated Li velocity	46 - 73 m/s
Angle of incidence	52±0.2 °
Nozzle size	14.3 mm
Orifice opening size	0.5 mm
Deflector type	Type 1 & 2

Thickness Measurement Result

- **632 ± 35 µg/cm^2**
- ± 5.5% for 1 mm spot diameter
- Physical thickness **12.3 ± 0.7 µm**





Next Steps

1. Ion beam on Li film
2. dc ~110 mA ion source from LANL
3. 75 keV
4. ~ 1kW to be deposited in Li film

Beta-beams

Very preliminary discussions with beta-beam collaboration