Simulation study of the liquid lithium target for the CiADS muon source

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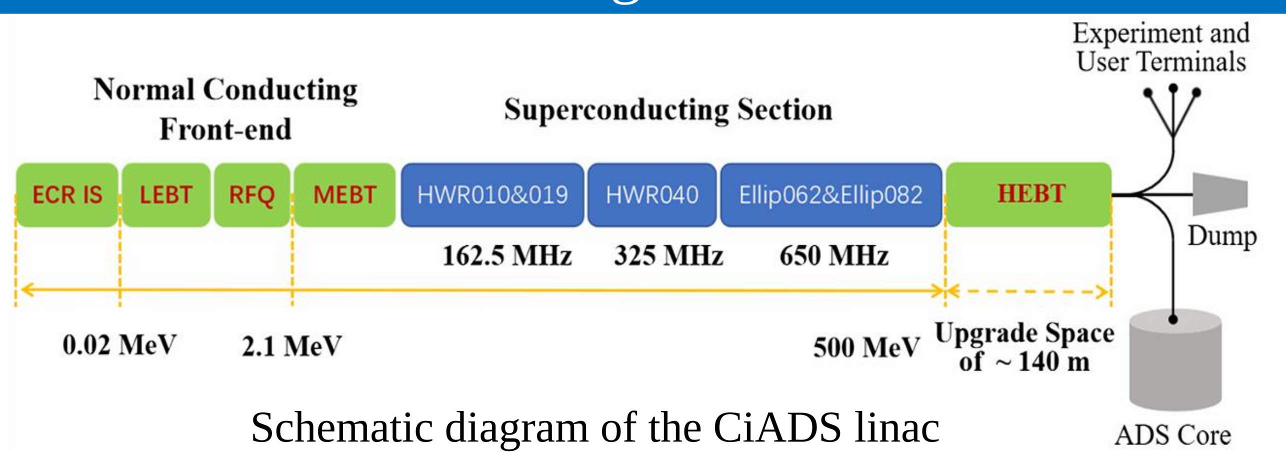
Introduction

To meet the requirement of the next-generation muon source driven by cw superconducting linac[1], a new solution of for the muon production target is essential. In comparison to the rotating graphite target, the free-surface liquid lithium target proposed in this paper offers advantages in surface muon production efficiency, heat-removal ability, and target geometry compactness. Owing to its properties of low melting point, extremely low saturated vapor pressure, high heat capacity, and good compatibility with structural materials, liquid lithium has been widely used as a neutron production target, a radionuclide production target, and an ion beam charge stripper. The stability of the jet is the key. Here the simulation study of the parameters for a stable lithium jet is introduced. The influence of the press fluctuation on the stability of the target body as well as the free surface is investigated.

Methods & Results

Background

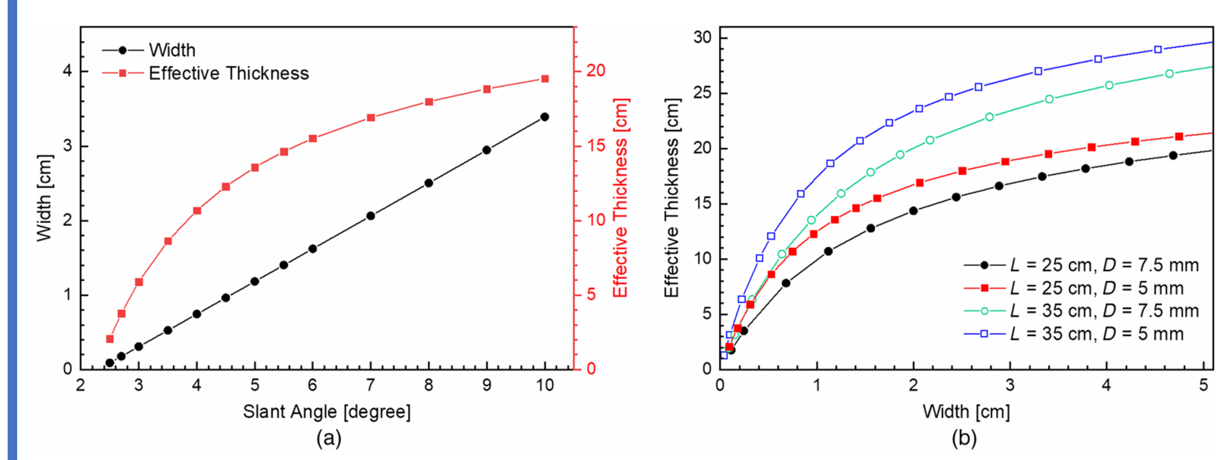


Schematic diagram of the CiADS linac

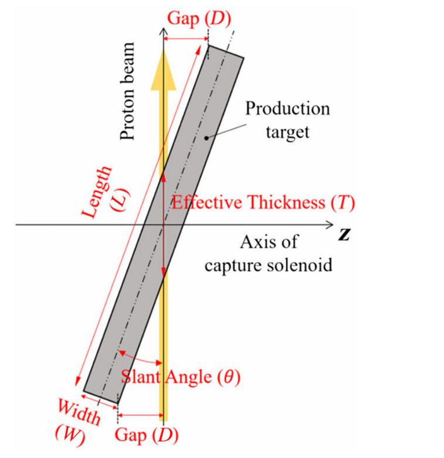
Site installations and equipment diagram of CiADS

Geometry optimization

It has been demonstrated that a significant gain of 50% or even more in the surface muon rate can be achieved by implementing a small slant angle on the slab target.



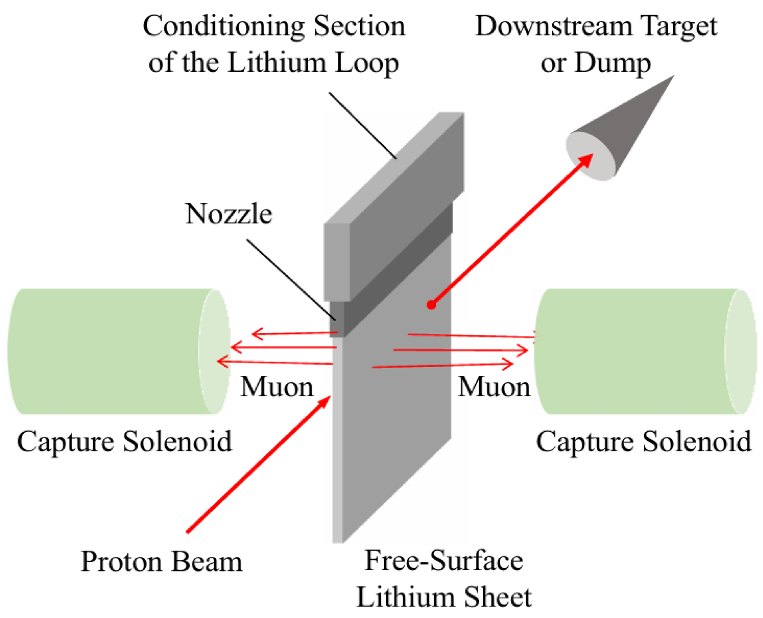
(a) Width (W) and effective thickness (T) as functions of slant angle for the jet with a length (L) of 25 cm, and a gap (D) of 5 mm.
(b) The effective thickness as functions of the width for four sets of L and D.



Here the length of 25 cm and the gap of 5 mm are chosen to investigate the surface muon rate.

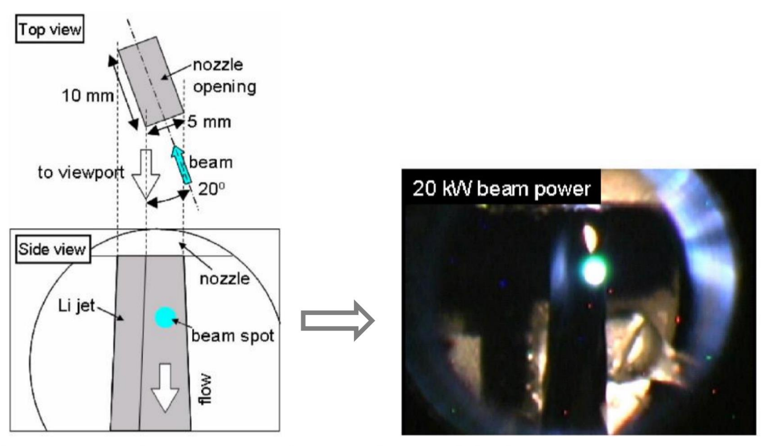
The free-surface liquid lithium target

- Pressurized liquid lithium flows through the conditioning section of a lithium loop and finally forms a sheet-shaped jet from the narrow nozzle.
- The proton beam is collimated to hit the lithium jet at a small angle, and surface muons produced in lithium escape from either side of the sheet, entering the capture field of the solenoids[2].



Schematic diagram of the free-surface liquid lithium target

- ➢ It has been experimentally proven that liquid lithium targets can be stabilized:



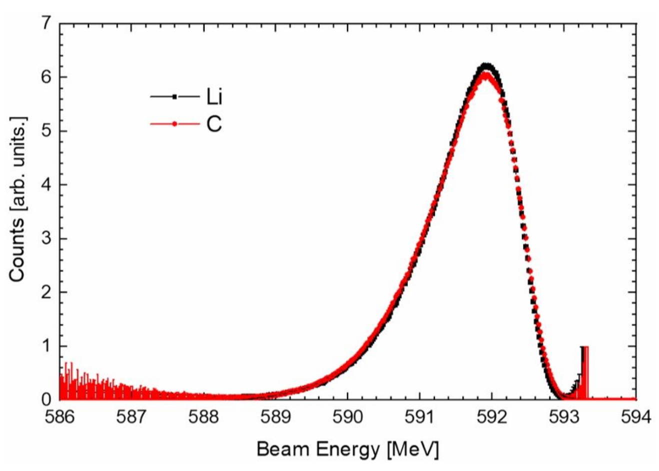
Schematic diagram of RIA liquid lithium jet target and photos of target hitting experiments[3]

Properties of liquid lithium

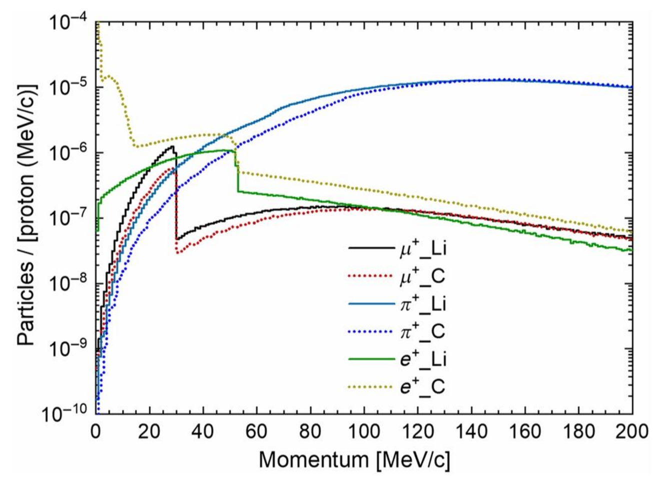
- ➢ low melting point
- ➢ low saturated vapor pressure
- ➢ high heat capacity
- ➢ good compatibility with structural materials

Comparison with graphite target

- ➢ Through FLUKA simulation, the energy distributions of the proton beams are almost the same after penetrating the two targets.
- ➢ It can be seen that the lithium target produces more low-energy $\pi+$ and, consequently, more surface muons than the graphite target, both at twice the rate of the graphite target, while the rate of positrons is much smaller.



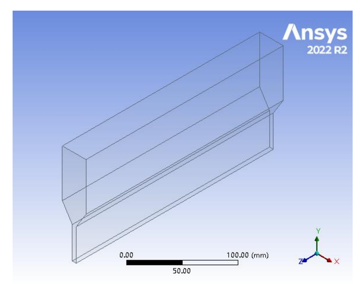
Energy distributions of the proton beams penetrating the 7.8-cm lithium target and the 2-cm graphite target



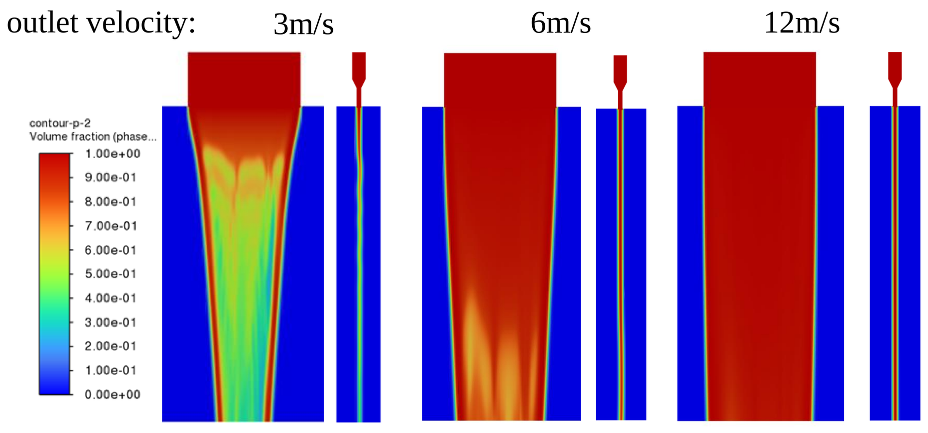
Momentum spectra of μ+and π+ and e+ recorded by the virtual detector det1 beside the target

Simulation methods and results

- ➢ In order to investigate the flow field of liquid lithium target, ANSYS fluent software is applied and based on
  - VOF (volume of fluid) method
  - k-e standard turbulence model
  - SIMPLE algorithm



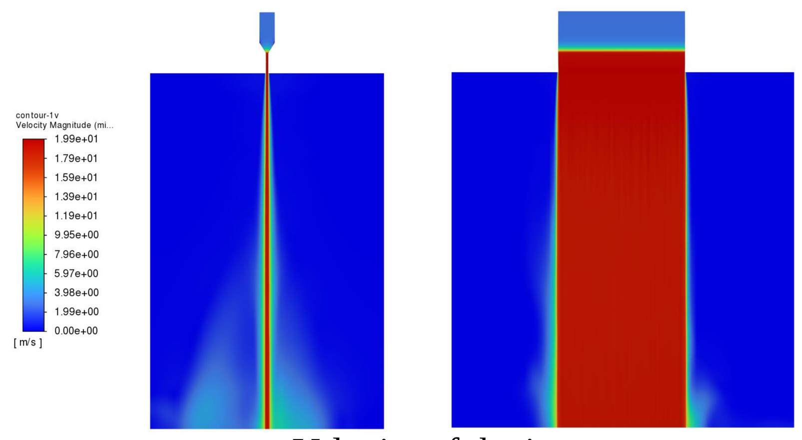
- ➢ The figure shows the vertical profiles (volume fraction) of 1 cm width lithium jets at the center for different exit velocities. When the outlet velocity reaches 12m/s, the target area can obtain a stable, vertically stable jet.



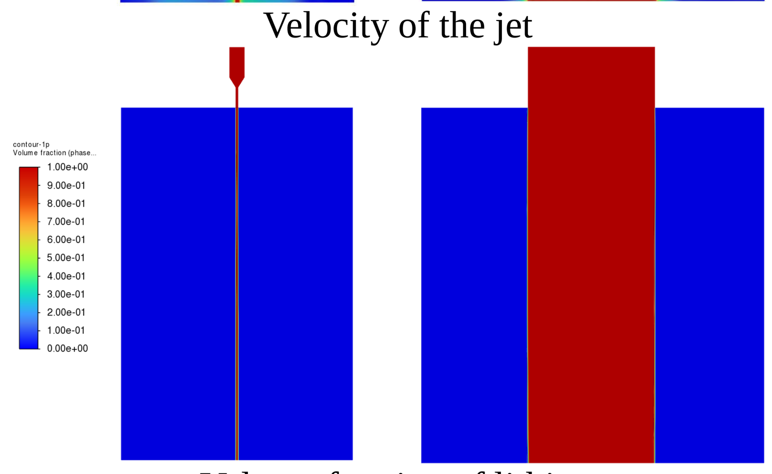
- ➢ Adjust jet width to 0.5cm, the inlet pressure increases to 0.1Mpa, nozzle outlet flow rate is about 19m/s, the outlet flow is stable and the liquid flow is flaky.

- operating temperature :473.15K
- pressure inlet :0.1Mpa
- pressure outlet :0
- Physical parameters of lithium:

Property	Lithium
Density(kg/m3)	515
Specific heat capacity(J/(kg·K))	3580
Thermal conductivity(W/(m·K))	43.49
Viscosity(kg/(m·s))	5.68×10^{-4}
Surface Tension(N/m)	0.325
Electrical Conductivity(S/m)	2.83×10^{6}



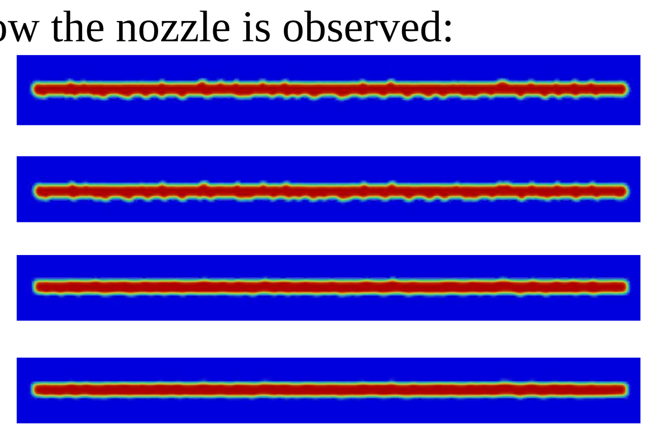
Velocity of the jet



Volume fraction of lithium

- ➢ Respectively, when the pressure inlet is 0.1Mpa, 0.2Mpa, 0.3Mpa and 0.4Mpa, the horizontal cross section of the free-surface jet at 150mm below the nozzle is observed:

It is found that when nozzle size is certain, with the increase of pressure, the smaller the cross-section sawtooth is, the smaller the fluctuation of the jet surface is.



Volume fraction of lithium

Conclusions

To meet the requirement of the next-generation muon source driven by cw superconducting linac, a new solution for the muon production target is essential. In com-parison to the rotating graphite target, the lithium jet target offers advantages in surface muon production efficiency, heat-removal ability, and target geometry compactness. Through the simulations of the liquid lithium target, we can prove that the outlet flow is stable, and with the increase of pressure, the smaller the cross-section sawtooth is, the smaller the fluctuation of the jet surface is. It can be preliminarily determined that under this pressure inlet condition, the spans of individual corrugations are all much smaller than the length of the jet, and when the beam is incident at a certain angle of inclination, the error of the effective penetration length can be controlled within 10%. Afterwards, a magnetic field will be added to the outside of the model to study the jet flow under the conditions of magnetic field influence.

References

[1] Wang, Zhi-Jun, et al. "Beam physics design of a superconducting linac." Physical Review Accelerators and Beams 27.1 (2024): 010101.
[2] Cai, Han-Jie, et al. "Towards a high-intensity muon source." Physical Review Accelerators and Beams 27.2 (2024): 023403.
[3]Nolen, J. A., et al. "Behavior of liquid lithium jet irradiated by 1 MeV electron beams up to 20 kW." Review of scientific instruments 76.7 (2005).