Liquid targets for isotope production

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CERN and University of Geneva

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High-Q and Low-Q pairs

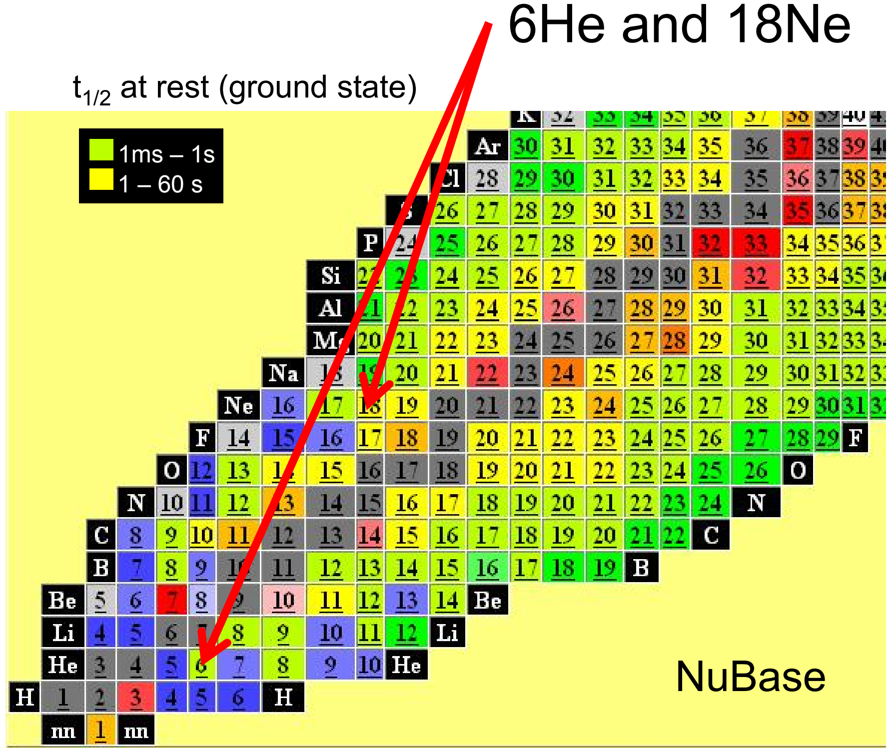
Isotope	^{6}He	^{18}Ne
A/Z	***3***	***1.8***
decay	β^-	β^+
$\tau_{1/2}$ ***[s]***	***0.81***	***1.67***
Q [MeV]	***3.51***	***3.0***

Isotope	^{8}Li	^{8}B
A/Z	***2.7***	***1.6***
decay	β^-	β^+
$\tau_{1/2}$ ***[s]***	***0.83***	***0.77***
Q [MeV]	***12.96***	***13.92***

8Li and 8B

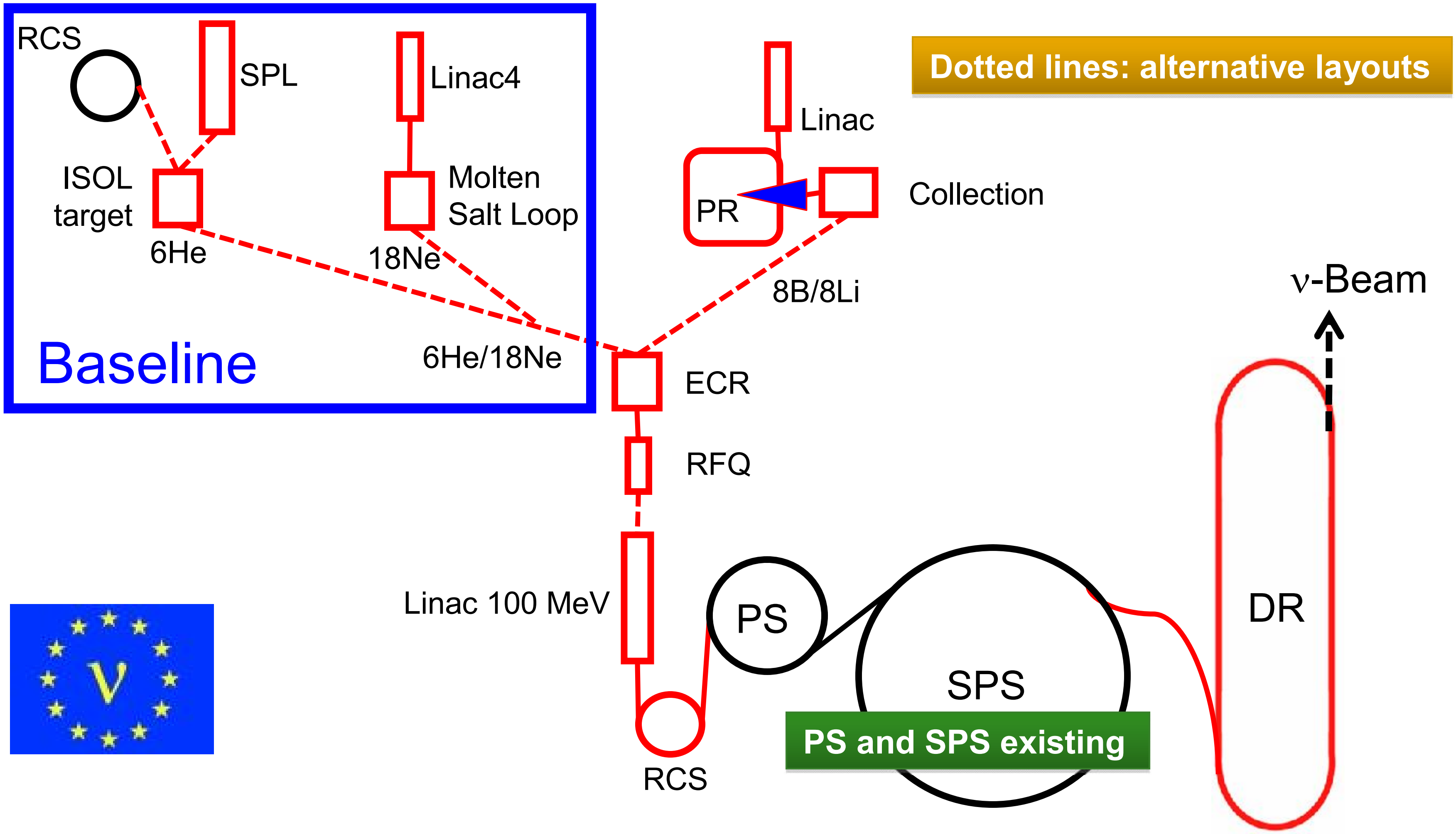
6He and 18Ne

$t_{1/2}$ at rest (ground state)



Higher Q-value gives higher ν-energy, better x-sections but needs longer baseline

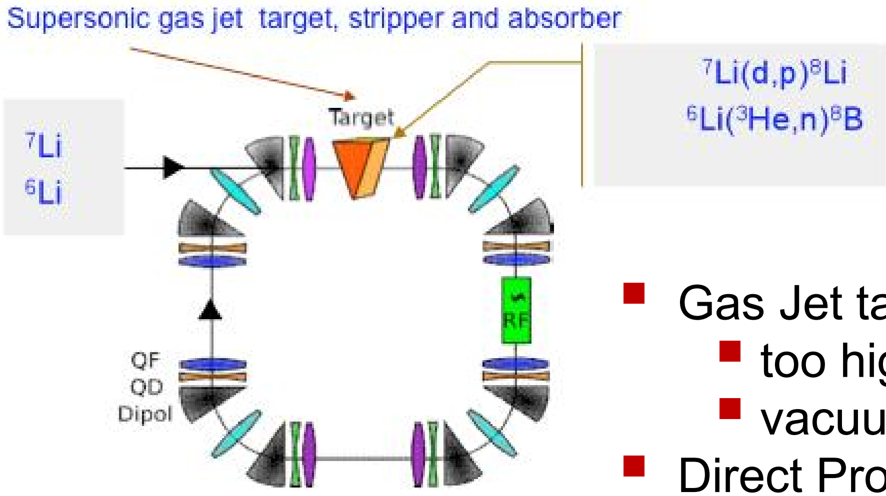
CERN Beta Beams, Synoptic



Decay Ring: Bρ ~ 500 Tm, B = ~6 T, C = ~6900 m, L_{ss}= ~2500 m, γ = 100, all ions

The Production Ring (8B and 8Li)

“Inverse”: ^{6}Li beam on ^{3}He gas jet. “Direct”: ^{3}He beam on ^{6}Li target.



Aachen Univ., GSI, CERN

Production of 8B and 8Li
C. Rubbia, EUROnu proposal

- Gas Jet target proposed in FP7:
  - too high density would be needed
  - vacuum problems
- Direct Production (D. Neuffer) with liquid film targets
  - Collaboration ANL (Benedetto/Nolen)

Can liquid lithium targets be used at the necessary power levels?

- High-Q 8B and 8Li will not be considered for the time being

- We will not explore the low-Q gamma 350 option

Direct vs. inverse kinematics

INVERSE

- ☺ ^{8}Li/^{8}B emitted at $\theta \sim 10^o$ similar energy as projectile
- 😐 Supersonic jet target
- ☺ Efficient cooling removal
- ☹☹ Low densities
- 😐 Collection + diff./effusion

DIRECT

- 😐 30^o emission angle and smaller velocity
- ☹ Larger M.C. Scattering
- 😐 Larger emittance, less SC
- 😐 Solid/liquid target
- ☹ Cooling / jet instabilities
- ☺ High densities
- 😐 Collection? Spectrometer?

See also D. Neuffer, NIM A 585 (2008) 109

Production/cooler rings: direct or inverse kinematics

114 D. Neuffer / Nuclear Instruments and Methods in Physics Research A 585 (2008) 109–116

Table 1
Low-energy ion cooling examples

Parameters for ion cooling for production of ^{8}B

Parameter	Symbol	Reverse dynamics	Direct scenario
Beam		^{6}Li	^{3}He
Absorber		^{3}He	^{6}Li
Momentum (MeV/c)	P	530	265
Kinetic energy (MeV)	T_a	25	12.5
Speed	$\beta = v/c$	0.094	0.094
Absorber density (reference)	ρ_{ref} (liquid or solid)	0.09375	0.46
Energy loss (MeV/cm)	dE/ds	110.6	170.4
Radiation length (cm)	L_R	756	155
Betatron functions at absorber (m)	$\beta_\perp, \eta$	0.3, 0.3	0.3, 0.3
Rms angle (°)	$\delta\theta_{rms}$ ($\beta_t = 0.3$ m)	$2.25K_s$	$3.8K_s$
Rms beam size (cm)	σ_t (at $\beta_t = 1$ m)	$2.15K_s$	$3.6K_s$
Absorber thickness (3000 turn lifetime) (cm)	λ_{abs}	0.018	0.00725
Characteristic cooling length (cm)	$(dP/ds/P)^{-1}$	0.45	0.147
Multiple scattering (cm^{-1})	$d\langle\theta^2\rangle/ds$	$8.84 \times 10^{-4}K_s^2$	$0.0078K_s^2$
Straggling (MeV^2/cm)	$d\langle\delta E^2\rangle/ds$	0.0886	0.143
Sum of partition numbers	$\sum J_i$	0.4	0.4
Eq. transverse emittance (m)	$\varepsilon_{T,N,rms}$	$4.35 \times 10^{-5}K_s^2$	$0.000123K_s^2$
Equilibrium $\delta P/P$ ($J_z = 0.13$)	δ_{rms}	0.0078	0.0115
Production energy (MeV)	$E_{B\text{-}8}$	8.3–21.5	0.93–8.3
Production speed	$\beta_{B\text{-}8}$	0.047–0.078	0.016–0.047
Maximum production angle (°)	θ_{max}	14	30

Recent presentation by the Argonne liquid lithium group

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

Presented at
4th High Power Targetry Workshop

May 2nd to May 6th 2011
Hilton Malmö City

Claude Reed, Jerry Nolen, Yoichi Momozaki, Jim Specht, Dave Chojnowski,
Ron Lanham, Boni Size, and Richard McDaniel

Nuclear Engineering Division and Physics Division

Thick target and thin target development

REVIEW OF SCIENTIFIC INSTRUMENTS **76**, 073501 (2005)

Behavior of liquid lithium jet irradiated by 1 MeV electron beams up to 20 kW

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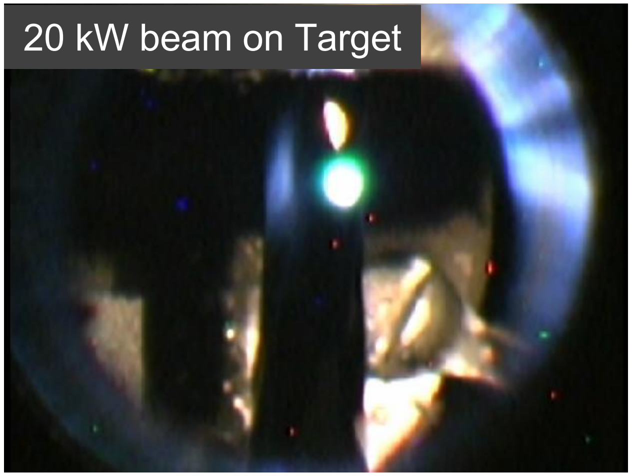

Development of a liquid lithium thin film for use as a heavy ion beam stripper *JInst 4:P04005 (2009)*

Yoichi Momozaki[a*], Jerry Nolen[b†], Claude Reed[a], Vincent Novick[a] and James Specht[b]

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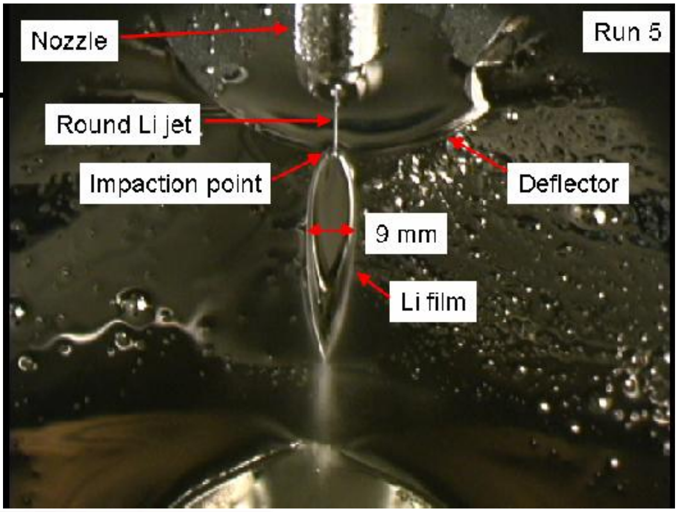
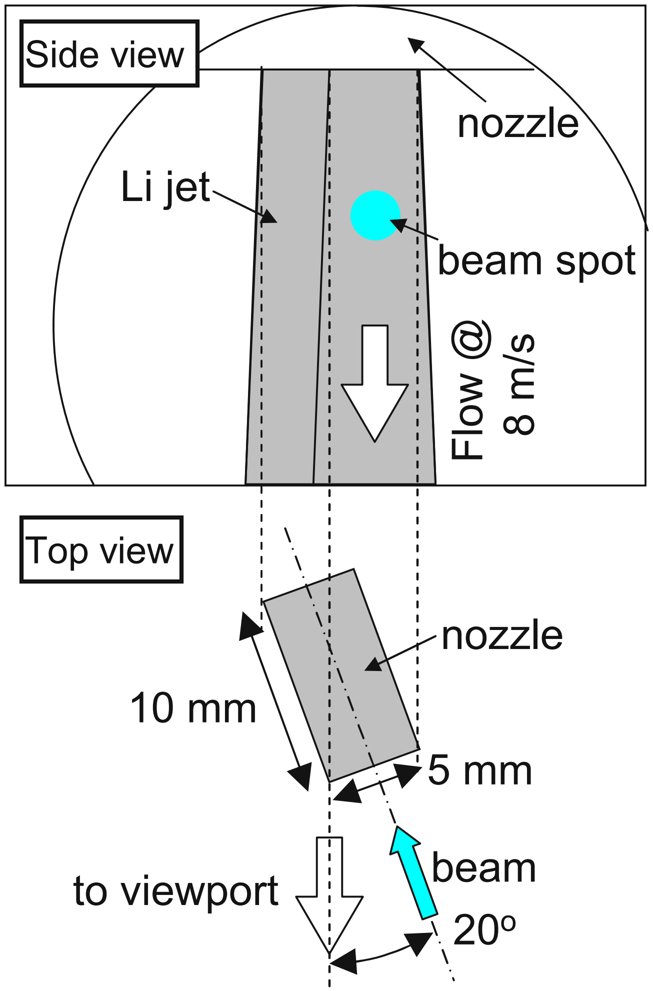
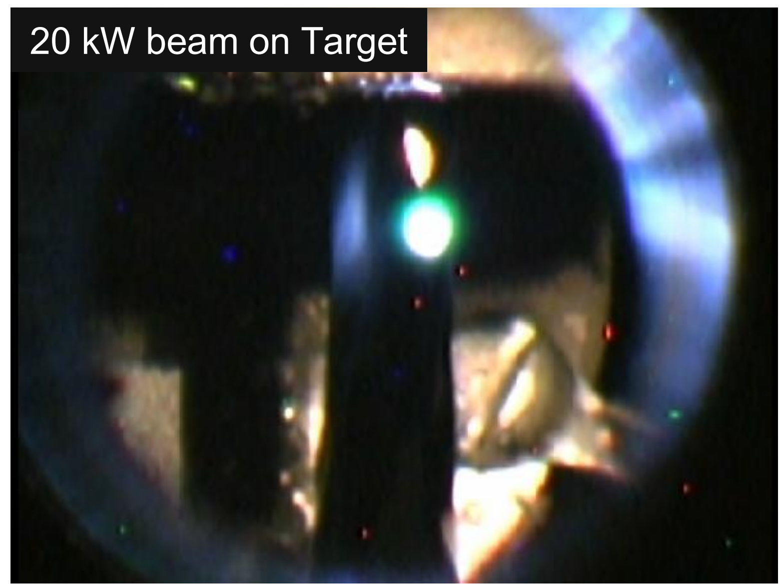


High Power Test of a Liquid-Lithium Fragmentation Target



A 20 kW electron beam produces the same thermal load as a 200 kW U beam on the windowless liquid Li target.

Li jet is confirmed stable in vacuum with a U beam equivalent thermal load.



Power density is 8 MW/cm^3 @ 400 kW beam power at 200 MeV/u.

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... for a brighter future

Thermal Design Analysis for Liquid Metal Windowless Targets

Y. Momozaki, J. A. Nolen, C. B. Reed, J. Bailey, and P. Strons

The Third High-Power Targetry Workshop

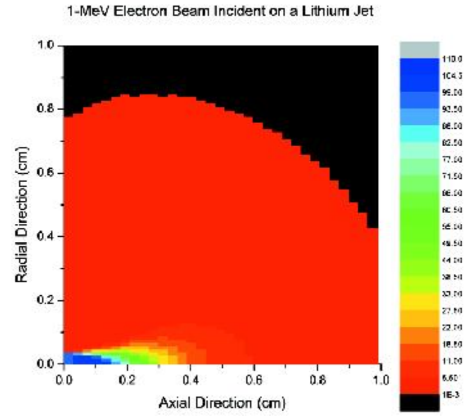
by Paul Scherrer Institut

September 10 to 14, 2007

Bad Zurzach, Switzerland

Background

20 kW E-beam-on-Target Test at ANL



- MCNPX :

  for RIA, 200-kW uranium beam on Li

  1MeV, 20 mA, 1mm ϕ e-beam on Li

  } peak energy deposition = 2 MW/cm^3 deposited in the first 4 mm

- Test Objectives:

  Using this equivalence, demonstrate that power densities equivalent to a 200 kW RIA uranium beam:

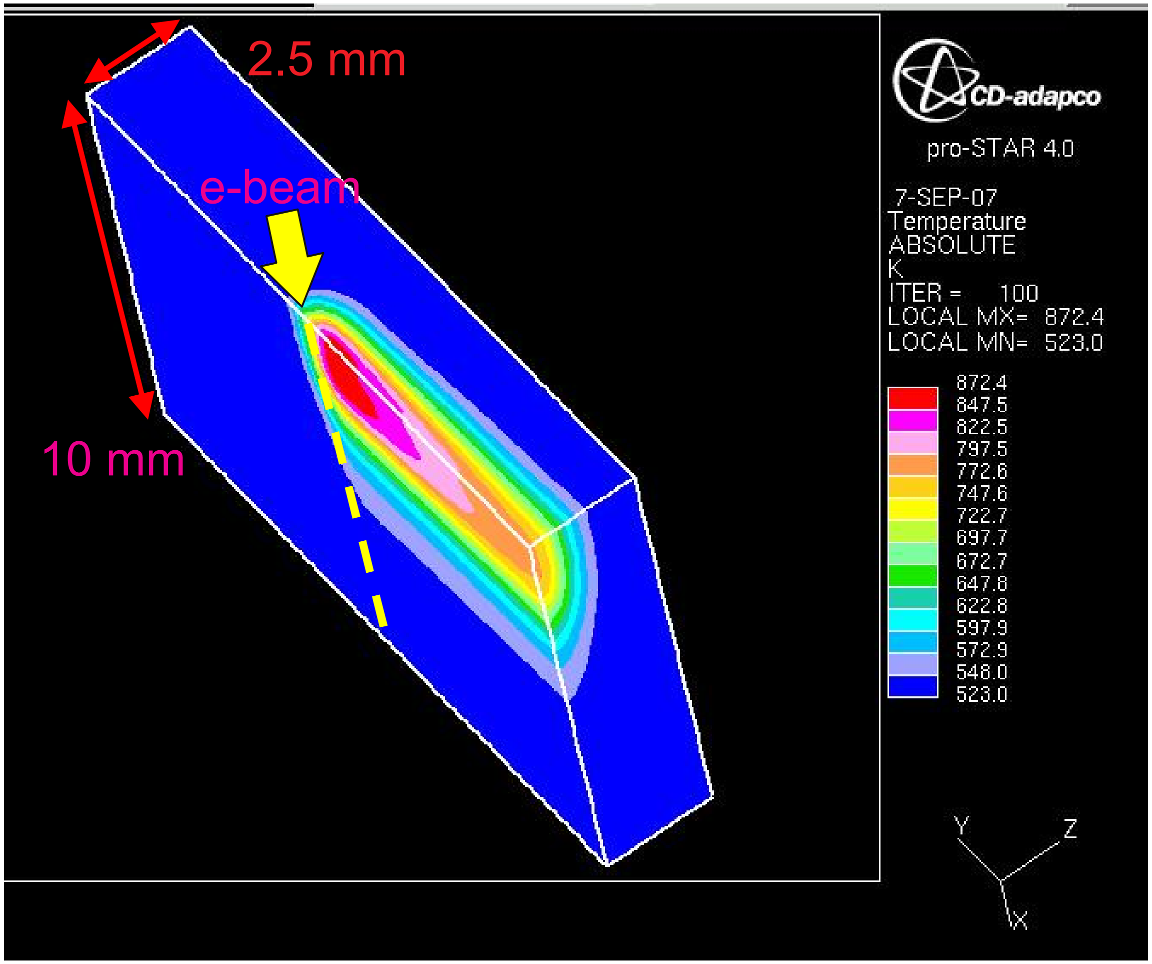
  - *Do not disrupt the Li jet flow*
  - *Li ΔT (across beam spot) is modest (~ 180º C)*
  - *Li vapor pressure remains low*

- Overall Objective:

  To show that 2 MW/cm^3, deposited in the first 4 mm of the flowing lithium jet, can be handled by the windowless target

What Experiment Indicates: power density for 1-MeV, 20-kW e-beam

- Thermal analysis
  - 3D Results (using Star CD)



- Estimated maximum temperature in the Li target is **872 K**.

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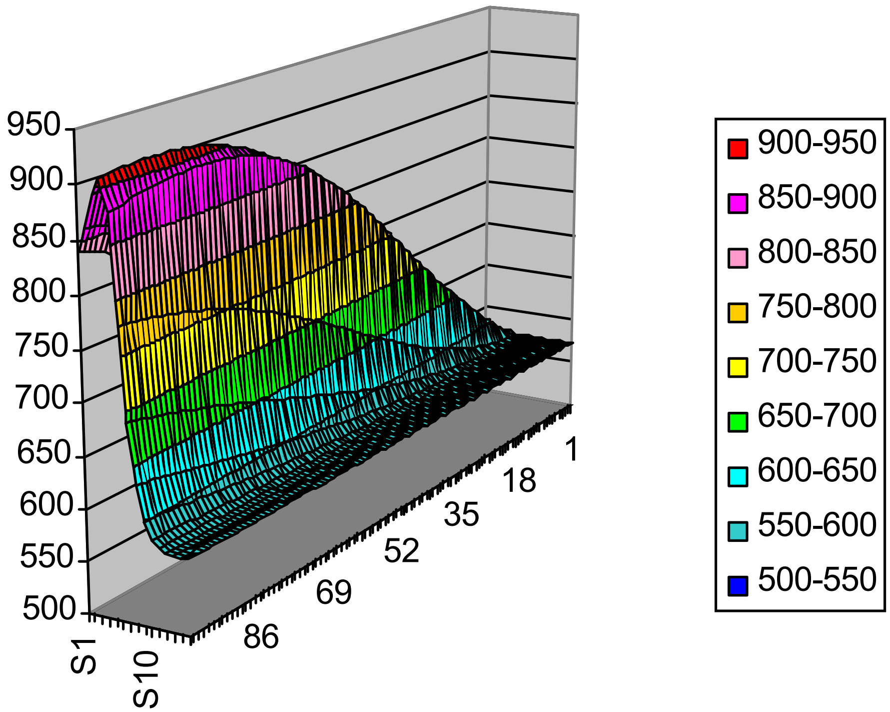
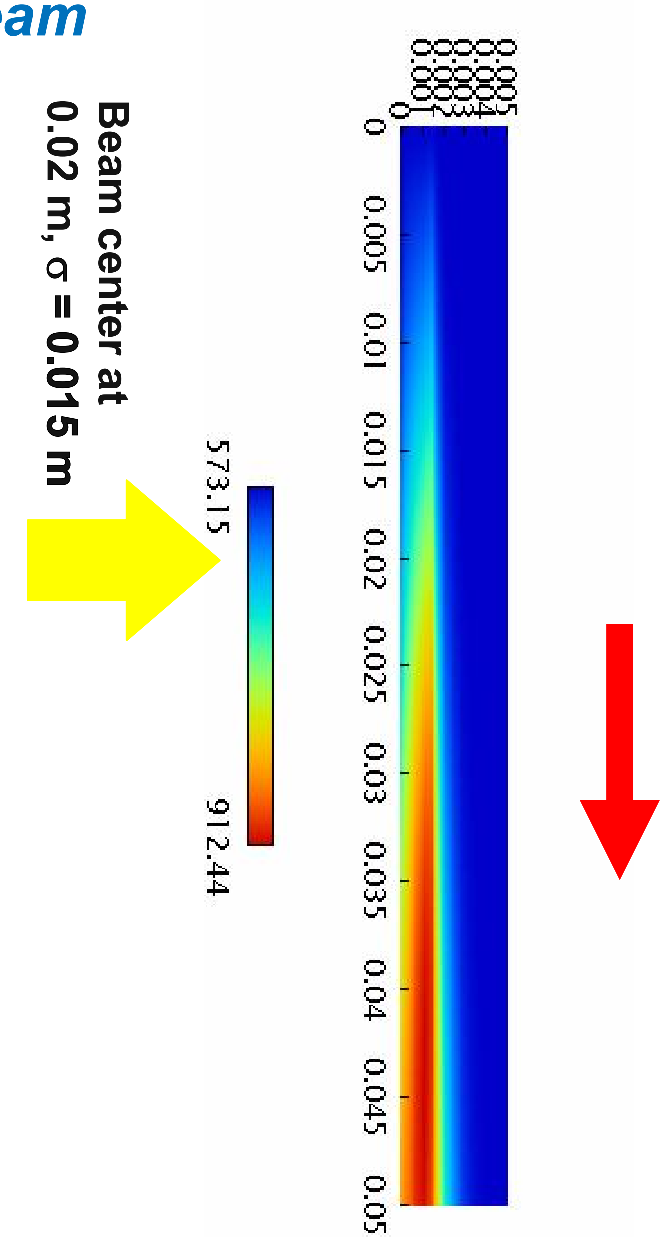
Thermal Design Analysis for a liquid tin beam dump for uranium beams

- Sn beam-dump for AEBL, ANL, USA





- Estimated maximum temperature in the Li target is **<u>912 K</u>** (<u>P_{sat} ~ 1.8×10</u>$^{-7}$ <u>Pa</u> for Sn).

Power density expectations give limitations for internal thin liquid lithium target size and speed

- Our prediction is for a peak temperature of 941K in a 13 micron thick film flowing at 58 m/s and 624 W deposited by a uranium beam with a 3σ beam width of 1 mm
  - Because of the high speed linear flow only the beam width is relevant
  - A 13 micron film is 0.65 mg/cm2, so a 1 mg/cm2 thickness can take 960 W/(mg/cm2) per mm of width
  - From David Neuffer's paper the internal target can be 3.6 mg/cm2 in thickness, and hence can take 3.5 kW per mm of width
  - He also predicts a power deposit from the ^{3}He beam of 500 kW, so the width of the beam spot must be 143 mm at 58 m/s to keep the same temperature rise
  - If we can increase the speed to 200 m/s then the width can be 41 mm
- Issues:
  - The beam spot can be 41mm wide by 1mm tall, so is this size beam on target compatible with the ring optics? (the slit-shaped beam is probably good for the recoil collection geometry)
  - Can we scale the speed to 200 m/s or more? (requires ~500 psia pressure – probably OK)
  - Can we make a film 41 mm wide and 72 microns thick? (I think so)

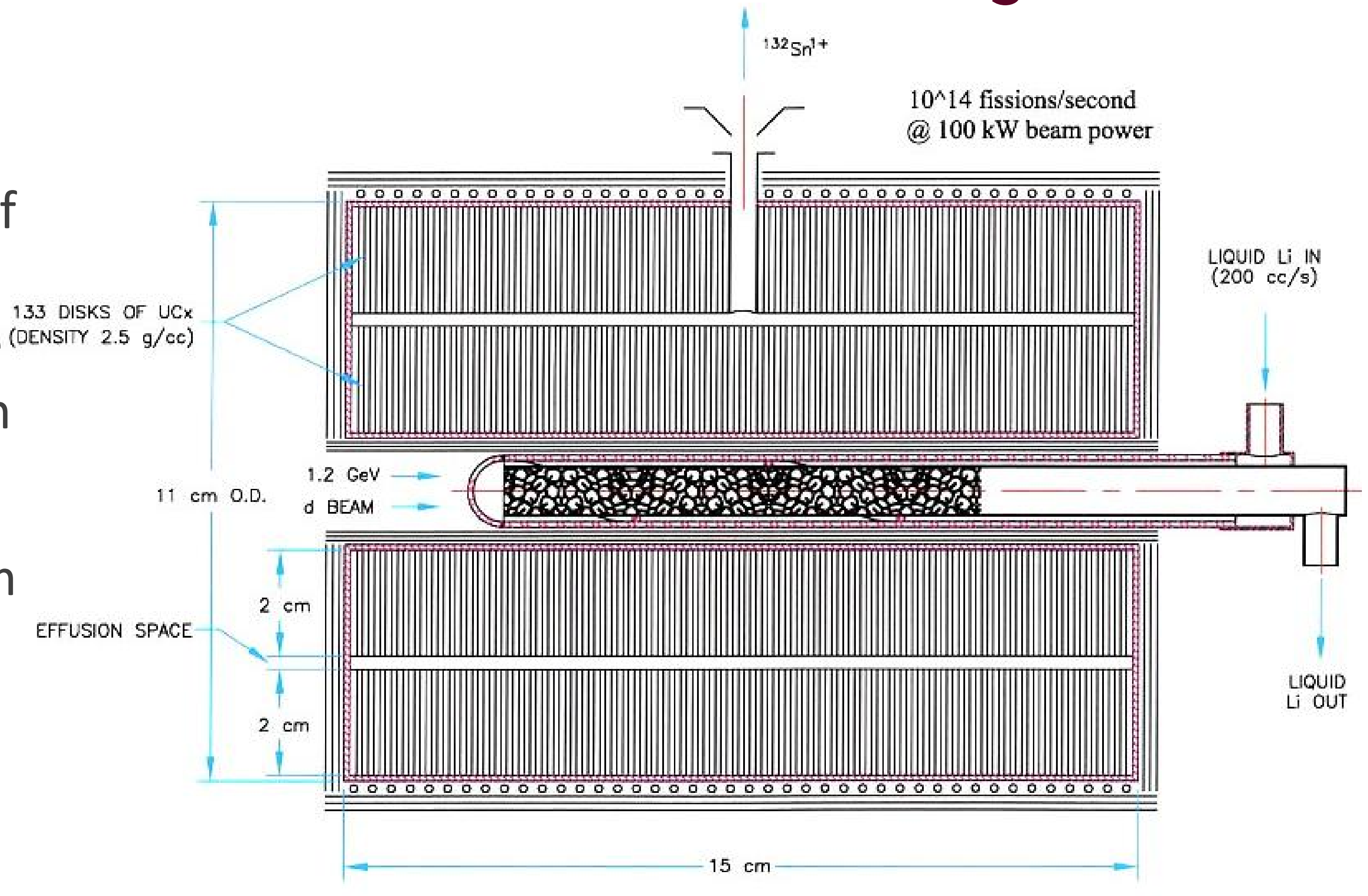
Other potential uses of liquid metal technology at neutrino factories

- Alternative for production of ^{8}B via fragmentation of ^{10}B
  - ~1 MW ^{10}B beam at ~200 MeV/u can produce in-flight 1E13 ^{8}B per second using a liquid lithium cooled target
  - The ^{8}B is formed at high energy and already fully stripped
  - Studies of transverse and longitudinal cooling are necessary to compare overall rates with “ISOL” methods
- The 2-step ^{6}He production target can probably benefit from liquid lithium cooling of the tungsten neutron converter
- The “pebble-bed” pion production target concept can probably benefit from liquid lithium cooling of the pebbles

Concept for a liquid-lithium cooled tungsten neutron converter for radioactive beams of fission fragments

This concept is applied to production of ^{6}He by replacing the uranium with BeO

Liquid lithium cooling enables a more compact geometry



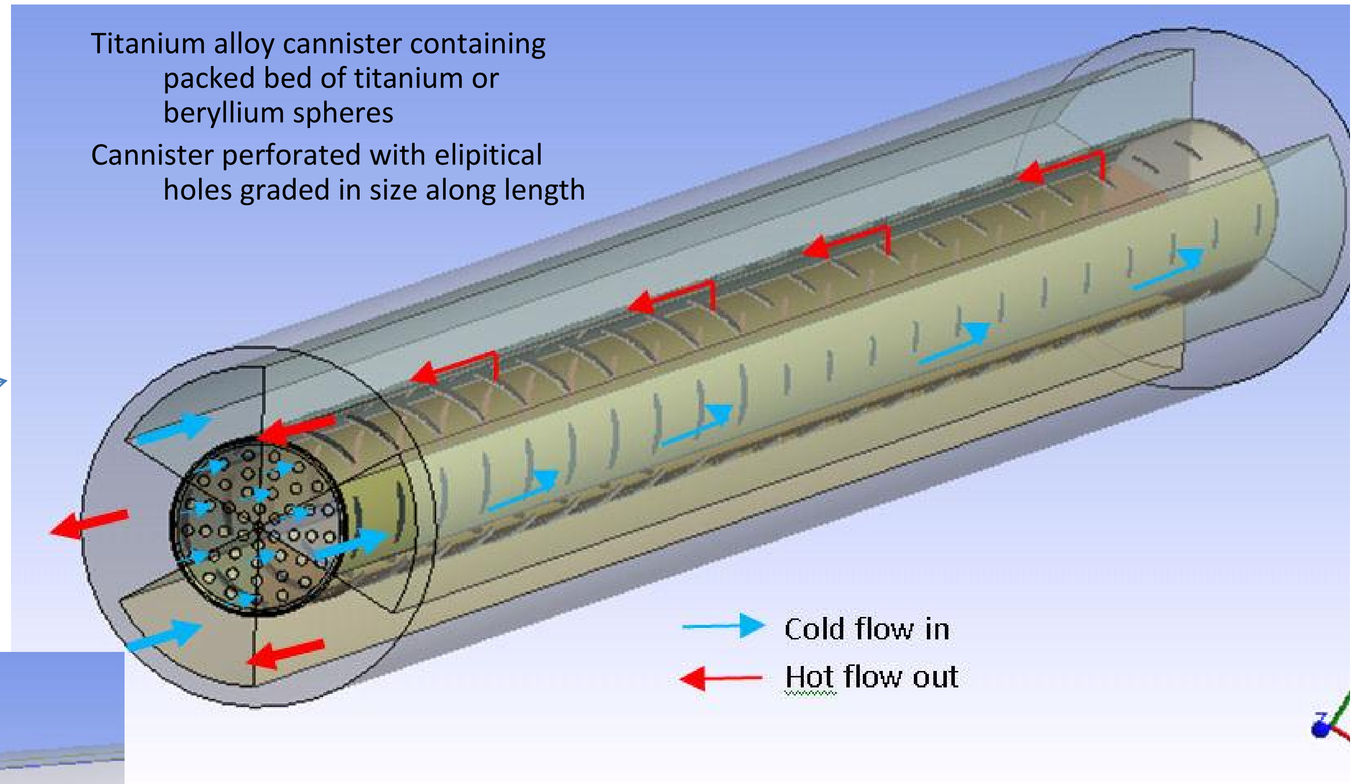
LIQUID-LITHIUM COOLED TUNGSTEN TARGET/ION SOURCE

Science & Technology Facilities Council

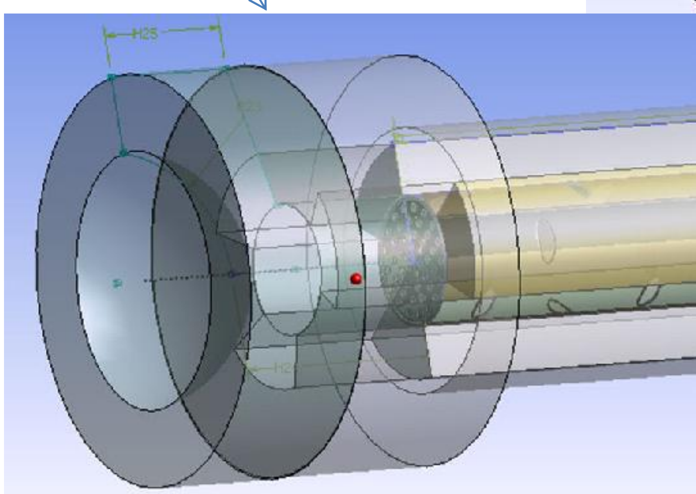
Slide from Tristan Davenne at EUROnu'11: Liquid metal cooling can be considered

Packed Bed Target Concept for Euronu (or other high power beams)

Packed bed cannister in parallel flow configuration



Packed bed target front end



Model Parameters
Proton Beam Energy = 4.5GeV
Beam sigma = 4mm
Packed Bed radius = 12mm
Packed Bed Length = 780mm
Packed Bed sphere diameter = 3mm
Packed Bed sphere material : Beryllium or Titanium
Coolant = Helium at 10 bar pressure

High Power Targets

Summary

- Initial estimates indicate that ^{8}B production via ^{3}He stored beam on a thin ^{6}Li target is not far from feasible (^{2}H beam on ^{7}Li target is less demanding)
- Beam-on-target tests of the thin lithium film is the next priority for the FRIB stripper development
- An update of the ring parameters required for necessary production rates should be done
- Ring and cooling/heating dynamics with a slit-shaped beam spot on target must be investigated
- Liquid lithium technology is possibly applicable in other aspects of neutrino factory targetry