Overview of requirements on targets

Preliminary study for muon production

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Introduction

Preliminary study for $\mu^+\mu^-$ production

The goal is the continuous muon production using target in a positron storage ring.
The main challenges on the target side are:

- steady state heat removal;
- avoid the material performance degradation in terms of μ production;

Criteria for target choice

Preliminary study for $\mu^+\mu^-$ production

The $\mu^+\mu^-$ pairs produced per interaction is:

$$N_{\mu^+\mu^-} = N(e^+)\rho_{e^-} L\sigma_{e^+e^- \to \mu^+\mu^-} \tag{1}$$

Where $N(e^+)$ is the number of e^+, ρ_{e^-} is the target electron density, L is the target length and $\sigma_{e^+e^- \to \mu^+\mu^-}$ is the cross section for the process.

- the ideal target is e^- dominated
- the dominant process is collinear radiative Bhabha scattering $(\sigma_{rb} \approx 150mb) \to (\rho_{e^-} L)_{max} = \frac{1}{\sigma_{rb}} \approx 10^{24} \div 10^{25} cm^{-2}$
- Muon beam emittance increases with L

Heavy and light materials

- minimize emittance $\rightarrow$ thin target
- maximize rate $\rightarrow$ maximize e^- density, high Z
- minimize e^+ loss $\rightarrow$ low Z

Heavy materials, thin target

- thin target to minimize $\epsilon_\mu \; \alpha \; L$, but high e^+ loss (Bremsstrahlung prevails), low $\mu^+\mu^-$ production efficiency $\eta_{max} \approx \frac{\sigma_\mu}{(Z+1)\sigma_{bhabha}} \approx 10^{-7}$

Very light materials, thick target

- maximize muons production $\approx 10^{-5}$
- even for liquid target $L \approx O(1m) \rightarrow \epsilon_\mu$ increase
- very hard power handling

Not too heavy not too light materials

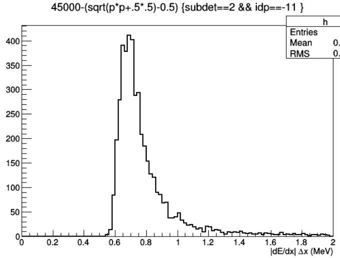
Not too heavy materials (Li, Be, C)

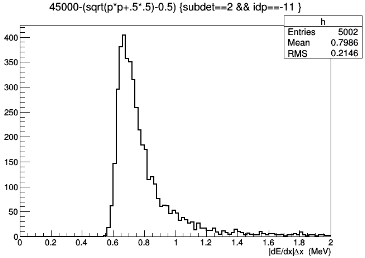
- combine low ϵ_μ and small e^+ loss
- muon production efficiency $\approx 10^{-6}$

$\rightarrow$ not too heavy and thin in combination with stored positron beam to reduce the requests on positron source

Deposited energy

The simulation of the deposited energy per particle using 10mm of lithium on the left and using 3mm of beryllium on the right.





Simple evaluation for instantaneous temperature increase

for lithium

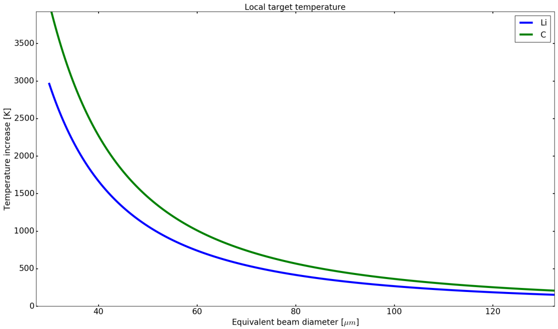
- $P_{target} = 1.6 \cdot 10^{-13} \frac{J}{MeV} \cdot 1.5 \cdot 10^{18} \frac{e^+}{s} \cdot 0.8 \frac{MeV}{e^+} \approx 200kW$
- $\frac{\Delta E}{e^+} = 0.8Mev \qquad \Delta V = 7.85 \cdot 10^{-5} cm^{-3}$
  - $\frac{\Delta E}{\Delta V} = 1.02 \cdot 10^4 \frac{MeV}{cm^3 e^+}$ Beam diameter $100\mu m$
- $\Delta T = 10^4 \frac{MeV}{cm^3 e^+} \cdot \frac{1}{0.512 \frac{g}{cm^3} \cdot 3.582 \frac{J}{g \cdot K}} \cdot 1.6 \cdot 10^{-13} \frac{J}{MeV} \cdot 3 \cdot 10^{11} \frac{e^+}{bunch} \approx$

$$2.7 \cdot 10^2 \frac{K}{bunch}$$

  - e-m shower contribution to the interactive volume is negligible

Temperature rise per single bunch vs beam size

Roughly estimation of the temperature rise per single bunch plotted vs the equivalent beam size



Beam size considerations

Beam size as small as possible (matching various emittance contribution), but constrains for:

- power density $\rightarrow$ the maximum temperature rise per bunch is a constrain for the beam dimension on target
- power removal $\rightarrow$ beam sweeping $\rightarrow$ crucial for the solid target option

The maximum temperature rise per bunch will fix the allowed pile up.

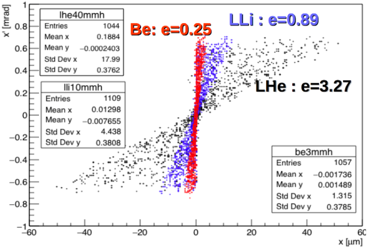
- Elliptical shaped beam $\rightarrow$ easier pile up handling.

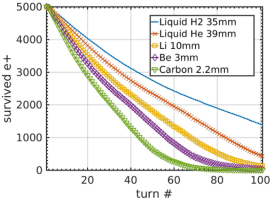
Assuming vertical beam size of $10\mu m$ the target vertical velocity is in the order of $50^{m}/_{s}$

Target contribution to μ beam emittance

- Thin light materials targets have negligible multiple scattering contribution, muon emittance is dominated by L

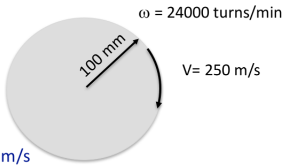
Be Beryllium
LLi Liquid Lithium, might be a good option (Proposed/tested for targets for n production)
LHe Liquid Helium





Rotating solid target

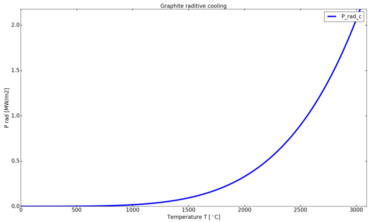
The well known rotating layout is the main proposal for the solid solution

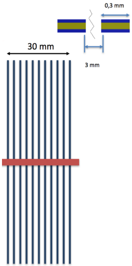


- Rotating disc
  - 24000 turns/min
  - Radial velocity V= 2 π ω(in turns) r=250 m/s
- Bunch spacing of ΔT=200ns
  - Bunch separation on target L = V ΔT= 50 μm
  - 12500 bunches in 1 turn

Graphite radiative cooling

The working temperature will set the needed surface for the radiative cooling → multilayer target in a copper comb to remove the radiated power





- mechanical and engineering difficulties increase with the operative target temperature (i.e. bearings, etc.)

Solid target summary

Advantages:

- conventional, well known technology
- few components → easier
- minimize L → low target emittance contribution

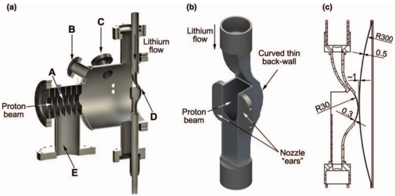
Disadvantages:

- something is moving at high speed in a very harsh environment
- dpa / material degradation / stresses
- limited lifetime
- power handling and cooling

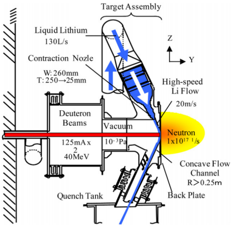
Status of the art → Muon production target E @ PSI

Flowing liquid lithium target

Few example in the world of flowing lithium target → LiLiT, IFMIF



(a) LiLiT vacuum chamber cross section: (A) set of 7 rings acting as lithium vapor trap, (B) view port, (C) port for beam diagnostics, (D) lithium nozzle, (E) arc-pump port; (b) and (c) lithium nozzle drawings (dimensions in mm).



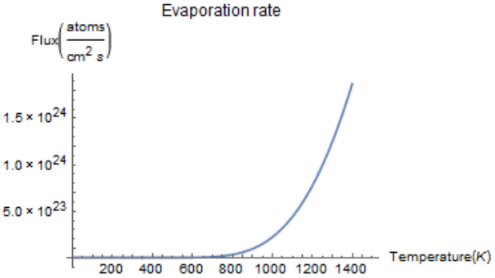
Request for our flowing lithium cascade:

- 10mm thickness in the interacting area
- $50 \, ^{m}/_{s}$ fluid velocity in the target area → no pile up for $10 \mu m$ vertical size beam

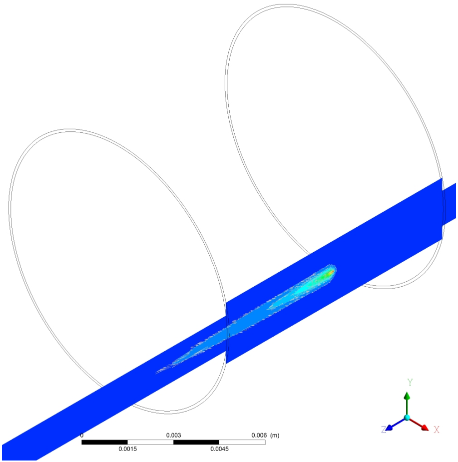
Evaporation issue

Evaporation flux must be take into account

- maybe needed for differential vacuum volume
  - very thin windows (Be, C?) $\rightarrow$ at O(m) the beam can be defocused up to O(cm)
- vacuum impedance, strong pumping capability, cold trap maybe are enough $\rightarrow$ it needs further investigation



Flowing Li thermal simulation



- The thermal simulations confirm the expected temperature rise
- Power handling seems feasible with lithium: the bulk temperature increase is very low
- Stable lithium jet interacting with the beam

Liquid target summary

Advantages:

- Power handling → $\approx 1.5 \cdot 10^4 cm^3 s^{-1}$ → O(10) degrees bulk temperature rise
- long lifetime target
- no expected degradation/dpa damage
- self healing/renewable flow

Disadvantages:

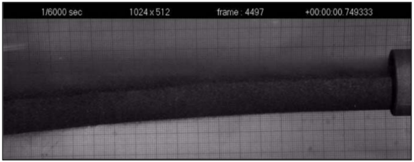
- no standard
- more pieces → more complex
- lithium handling → safety system
- impact on vacuum has to be verified, maybe it needs differential vacuum box → complexity increase

Status of the art → IFMIF / LiLiT @ SARAF

Hybrid solution → powder flow

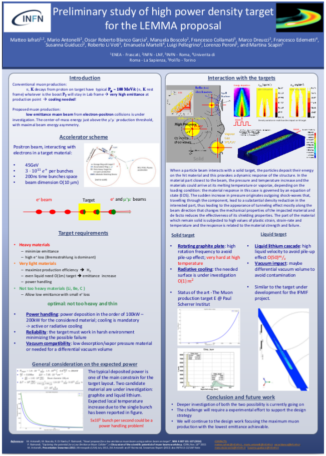
Powder continuous recirculating flow has been taken as a possible solution.

- no studies have been performed on this opportunity yet
- this concept is already in use, mainly with high Z materials (i.e. W)
- wear of parts and powder
- containment and main vacuum contamination



Status of the art → O. Caretta et al. @ RAL / CERN

Preliminary study for LEMMA target



A poster showing the preliminary study on LEMMA target has been presented @ HPTW 2018

- The community addressed it as an interesting and challenging topic
- We are in contact with the Israeli colleagues @ Soreq Nuclear Research Center, expert in liquid metals targets

Conclusions and future work

Conclusions:

- Main target requirements
  - power handling
  - reliability
  - beam compatibility
- Alternative layout strategies
  - solid
  - liquid flow
  - dust/powder flow

Future work:

- Deeper analysis of the proposed layout and engineering design
  - solid $\rightarrow$ design and calculations
  - liquid $\rightarrow$ flow and stability simulations, conceptual scheme design
  - powder $\rightarrow$ preliminary estimations
- Experiments needed:
  - Test the maximum operating temperature and cooling capability for rotating target
  - Liquid lithium interaction with very high power density beam

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