Simulation and Beam Studies for µCF: Current Results and Future Challenges

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Workshop on μCF and Future Applications

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UNIVERSITY OF LIVERPOOL

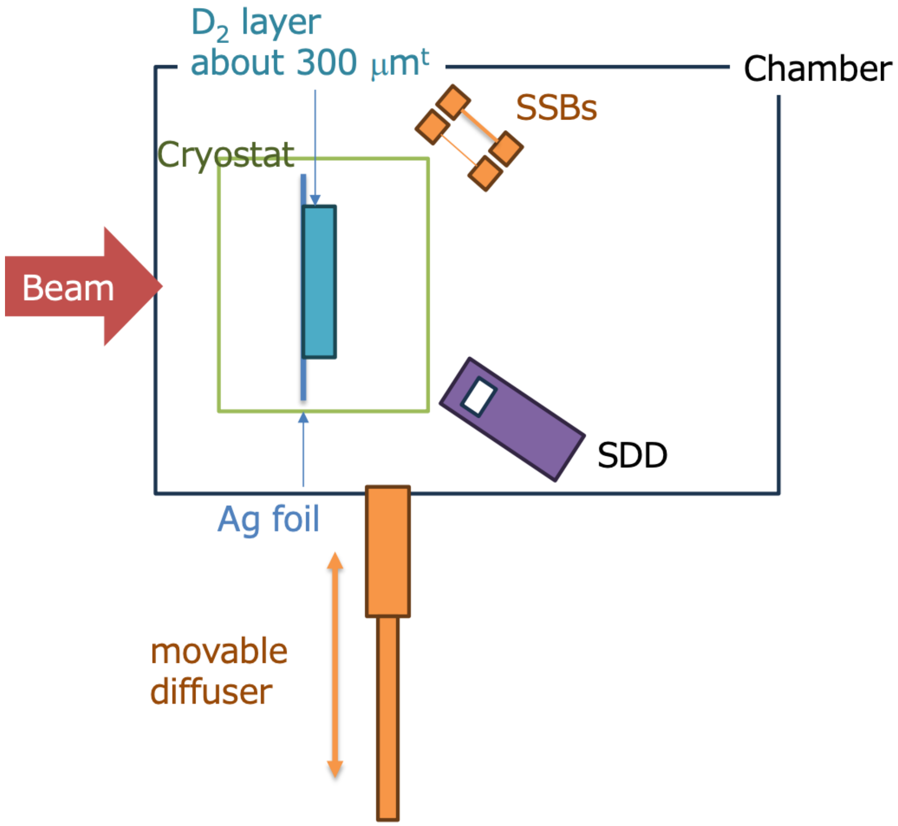
LEVERHULME TRUST

MOONSHOT RESEARCH & DEVELOPMENT PROGRAM

Introduction

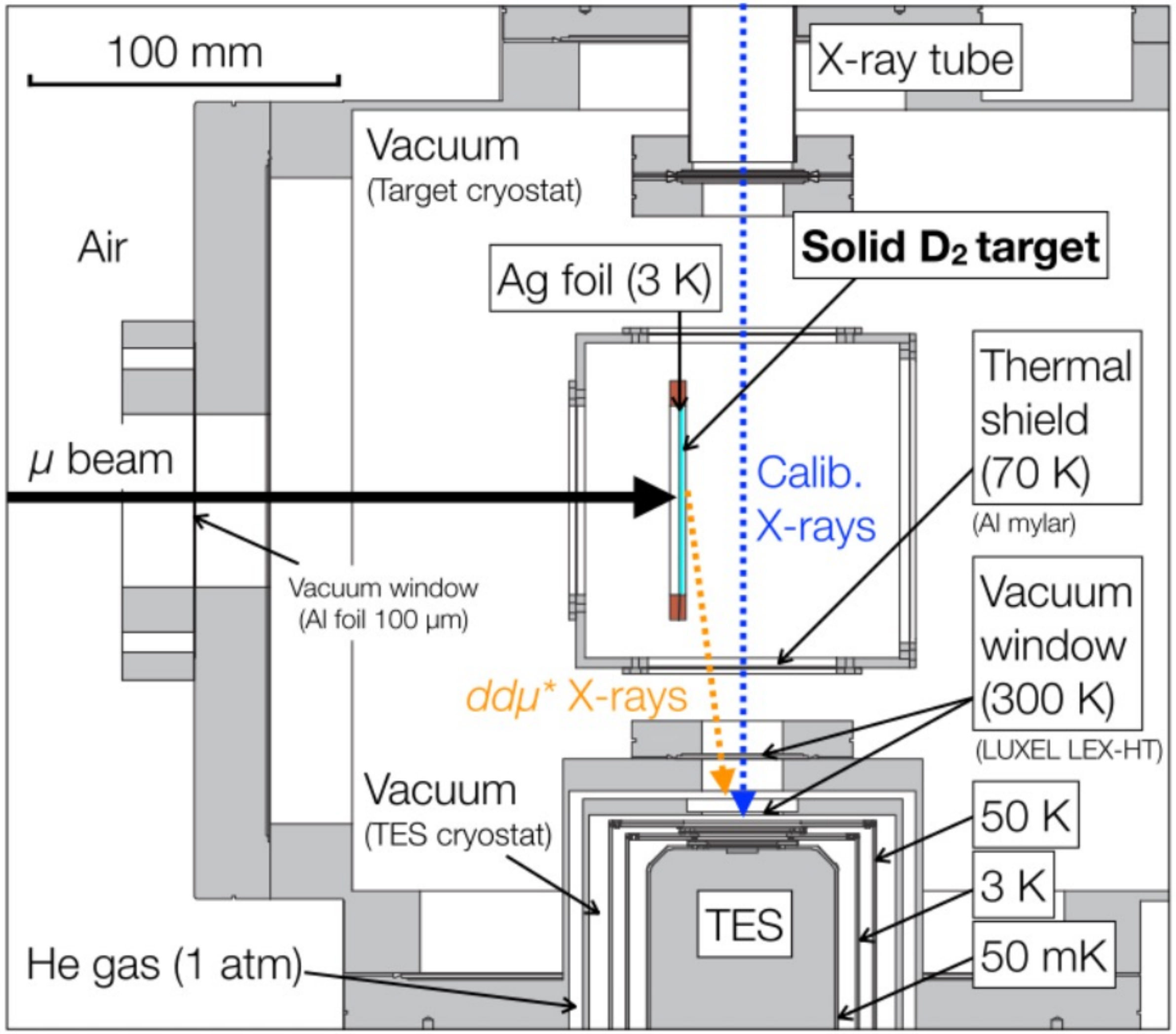
- The previous experiment at J-PARC MLF (D2) area measured dd-muCF process
- It was unable to measure fusion proton background.
- The plan is to continue preparations for the deuterium **(D2) target experiment**. And also planning to perform TES X-ray spectroscopy using a **tritium (T2) target** in the future.

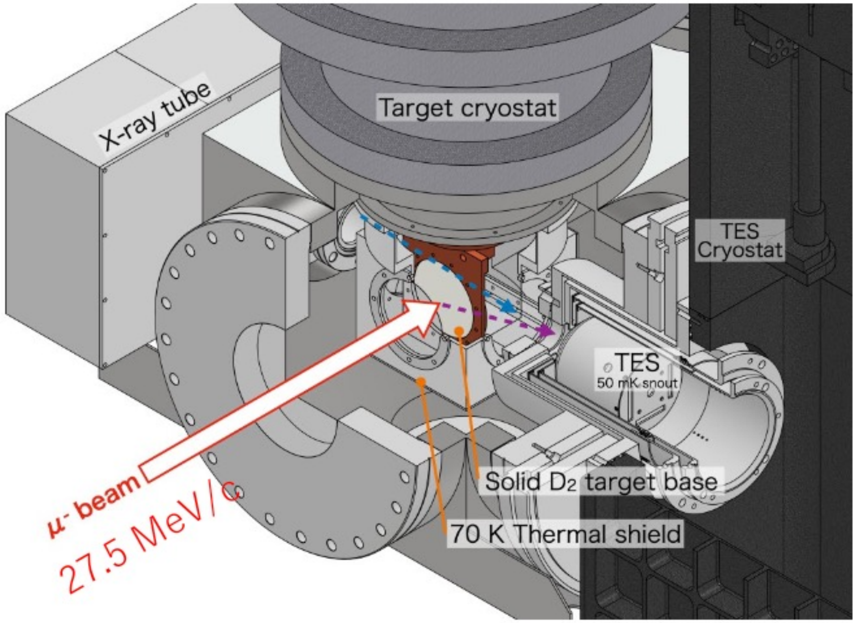
dd-muCF setup



setup drawing courtesy: Toyoda-san

Previous D2 experiment (Mar. 2023)



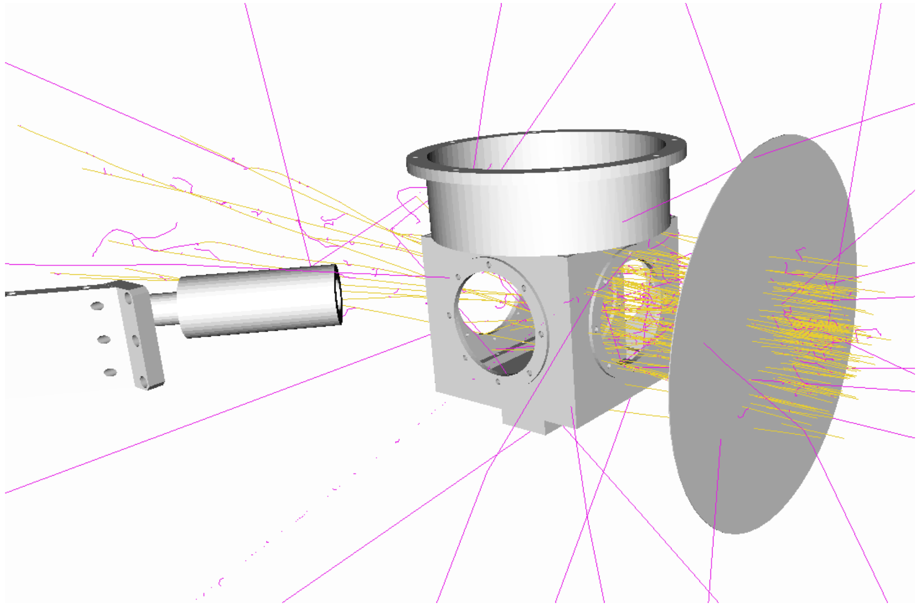


Materials

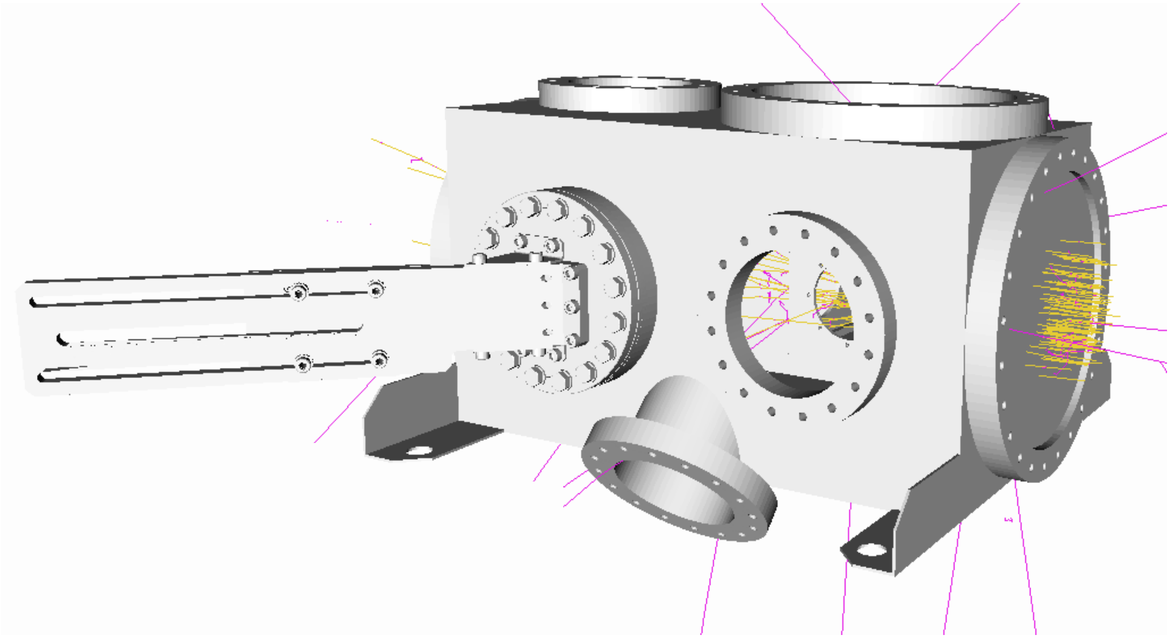
- Beam duct window: Kapton 100μm (not 100% sure)
- Air between the beam window and the chamber window: ~20 mm
- Chamber vacuum window: Al 100μm
- Thermal shield window (front & back): Al 11μm
- Thermal shield window(sides): Mylar 2μm + Al (vapor deposition) 0.2 μm
- Ag foil (target base): 100μm
- Solid D2: ~1 mm

Experimental setup and Geant4 model

- We have step-by-step implemented: target holder, chamber, and SDD detector into the Geant4 models



Model 1 (simplified model) for easily view the beam performance



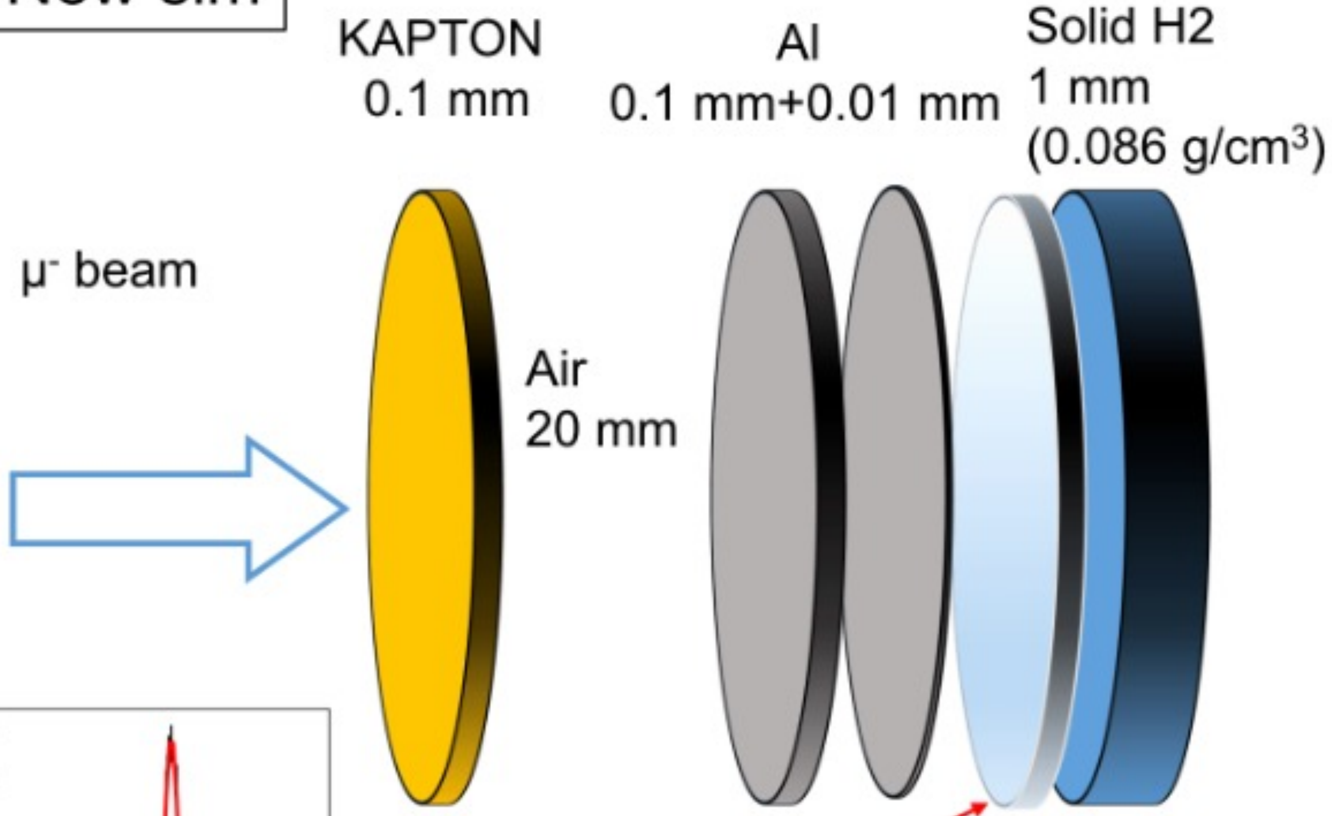
Model 2 (full model) with the entire chamber and supporting structure

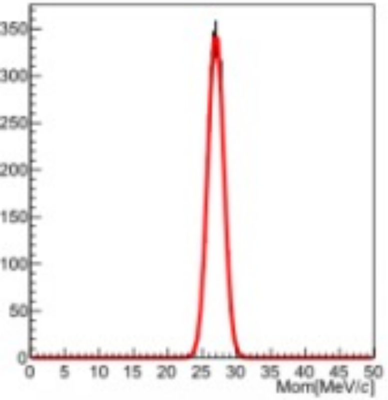
μ stop probability (Solid H2 target, Ag folder)

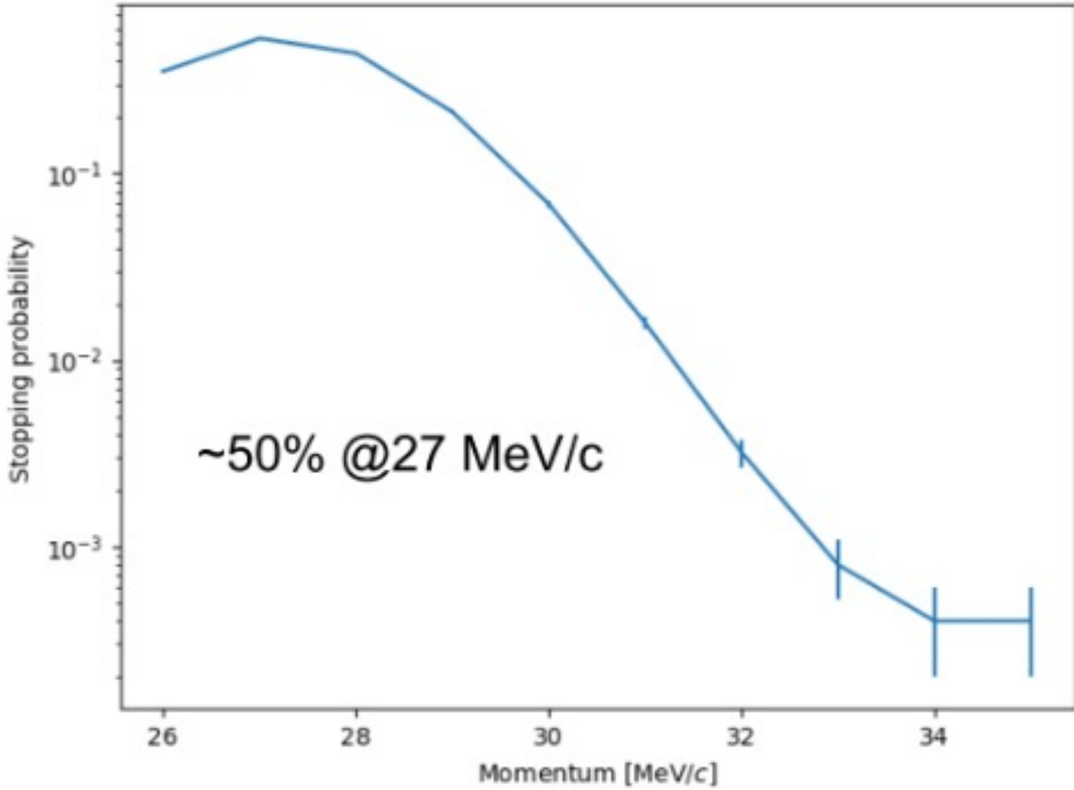
slides courtesy: Toyama-san

Beam size is not considered

New sim



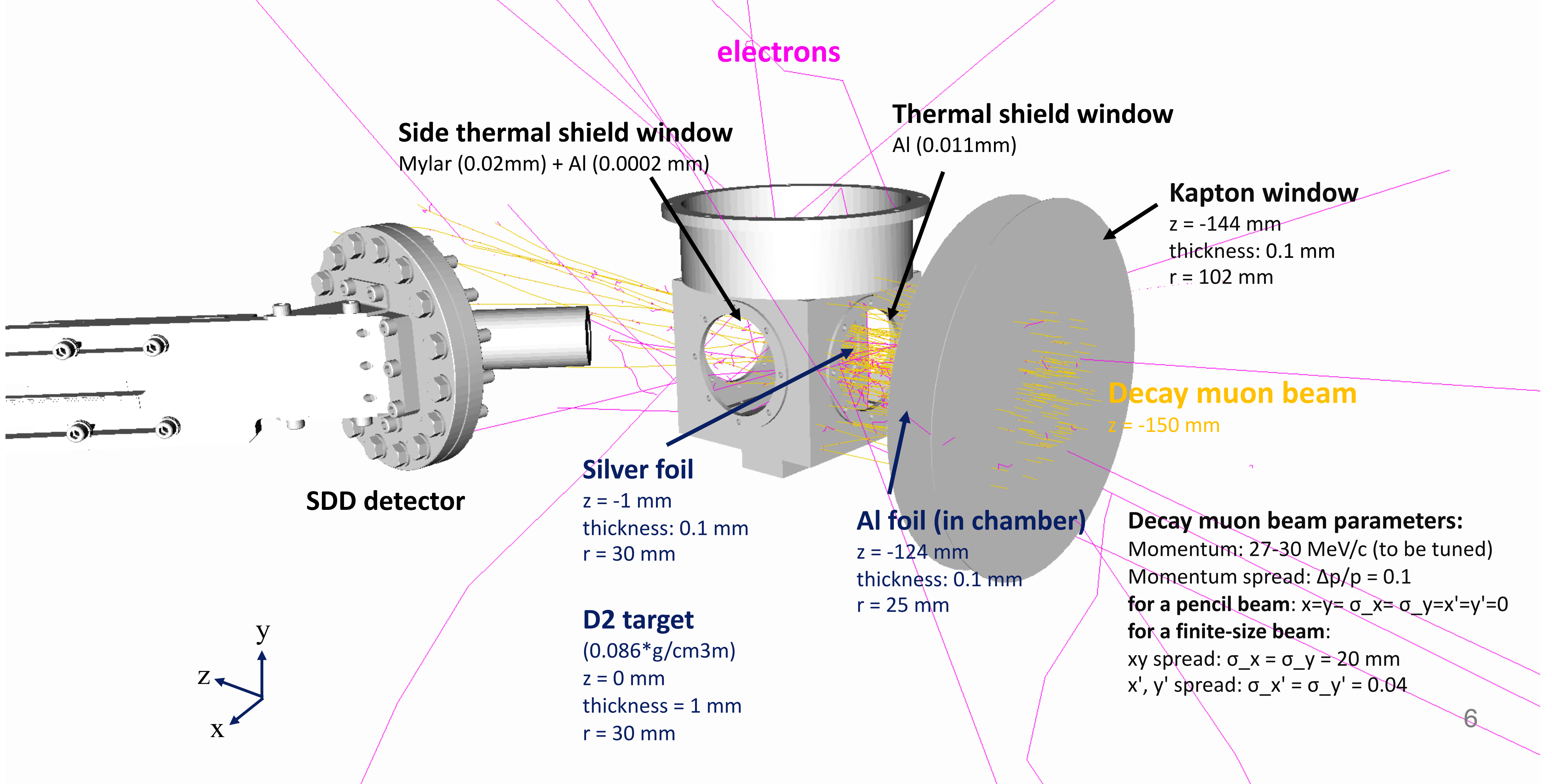




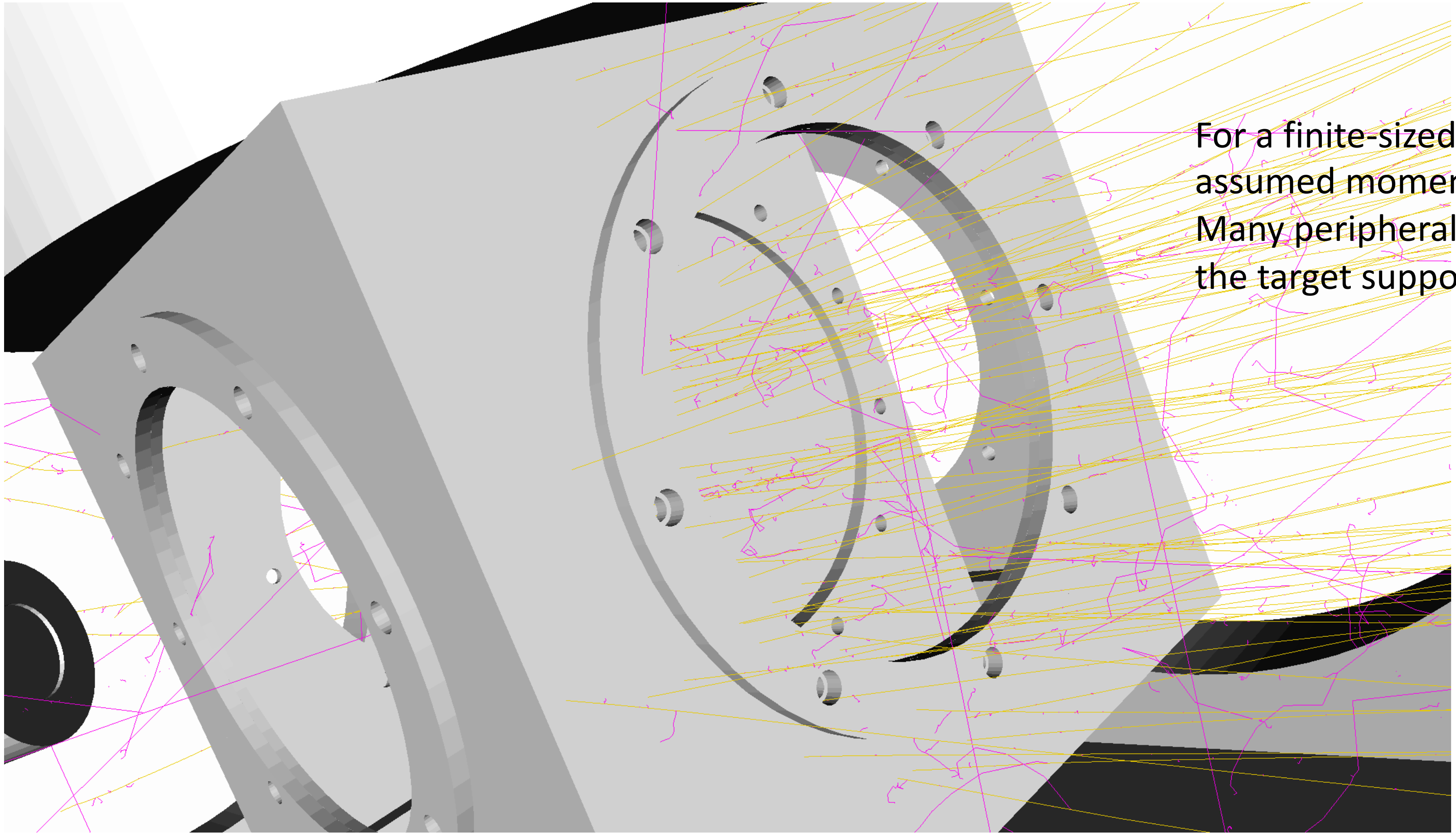
Ref: 14% by PHITS

(K. Okutsu et al., Fusion Engineering & Design170 (2021) 1127

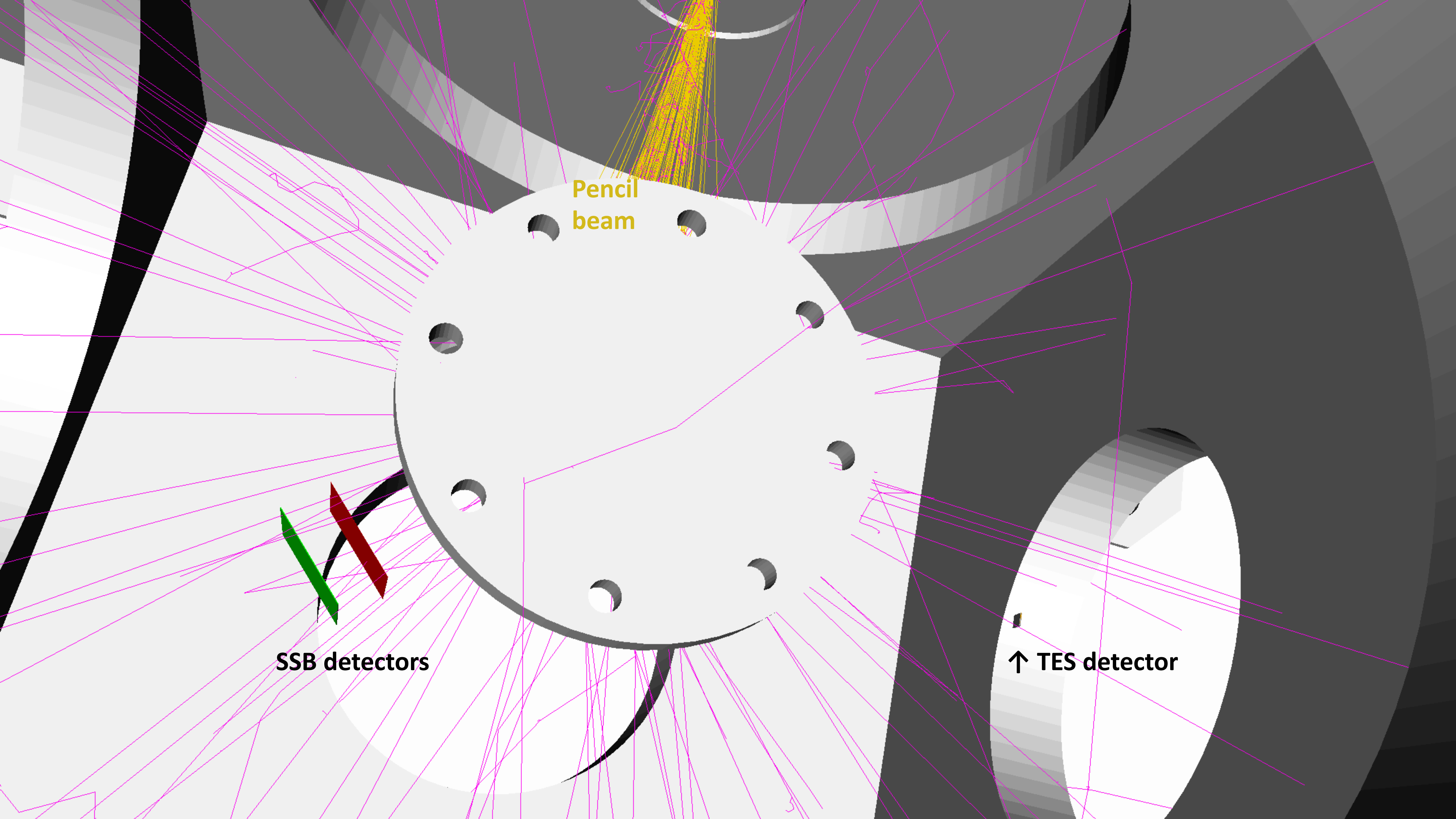
Thanks to Toyama-san's information, the stopping simulation has been performed with Geant4 model



Finite-size Beam vs Pencil Beam

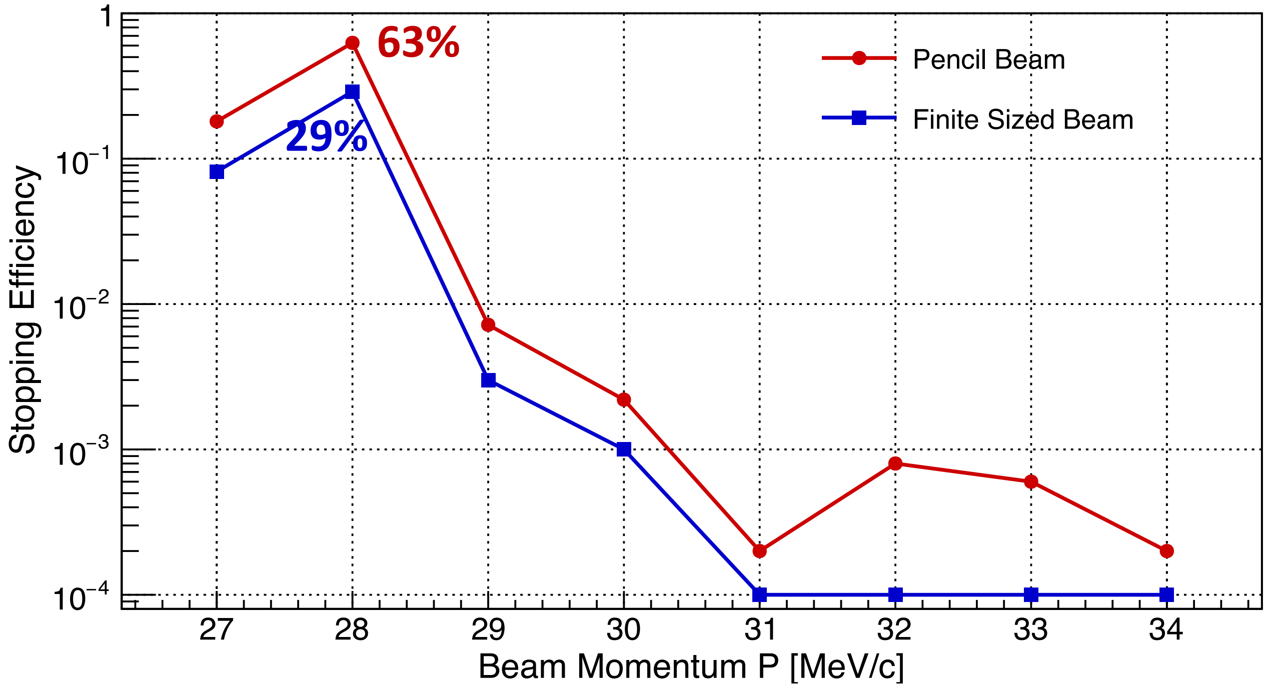


For a finite-sized muon beam, the assumed momentum spread is too large. Many peripheral muons are stopped by the target supporting structure


Pencil beam
SSB detectors
TES detector

Stopping simulation at Geant4

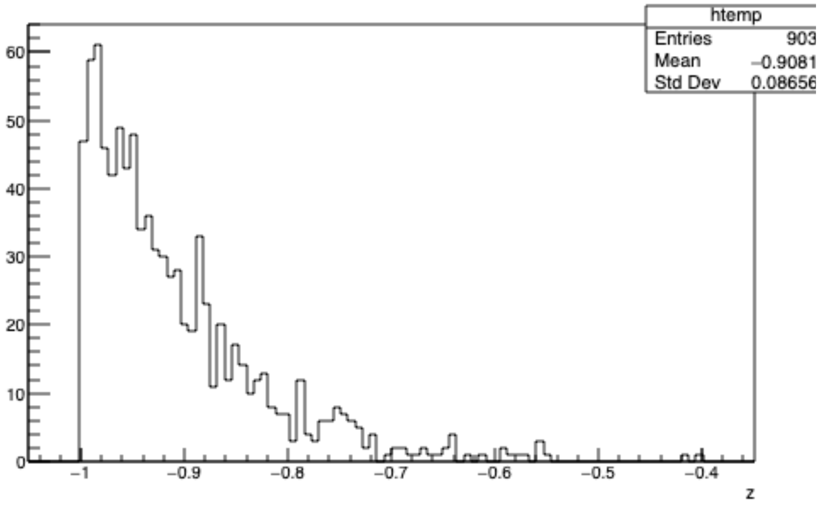
- Strategy is to scan the decay muon momentum (27 – 34 MeV/c)
- Pencil beam shows 60% efficiency @ 28 MeV/c (solid D2 target)



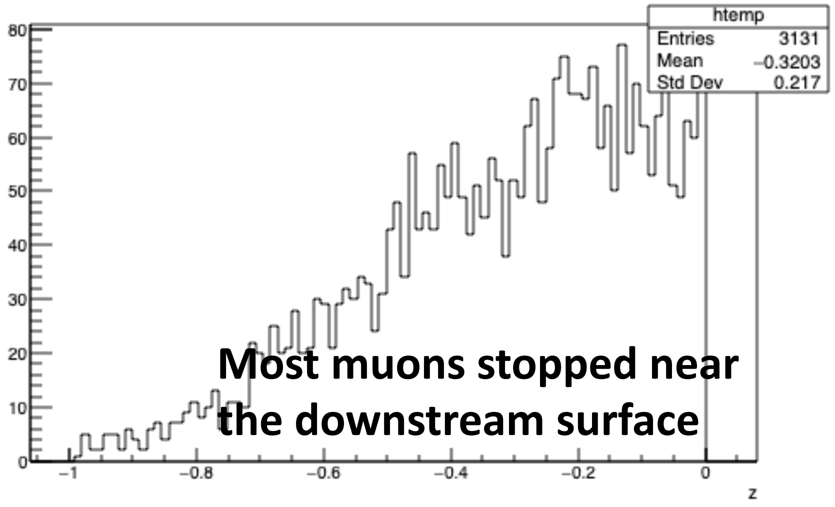
- Later studies will be based on using 28 MeV/c muon beam

Stopping simulation at Geant4

- Z vertex distributions (pencil beam)

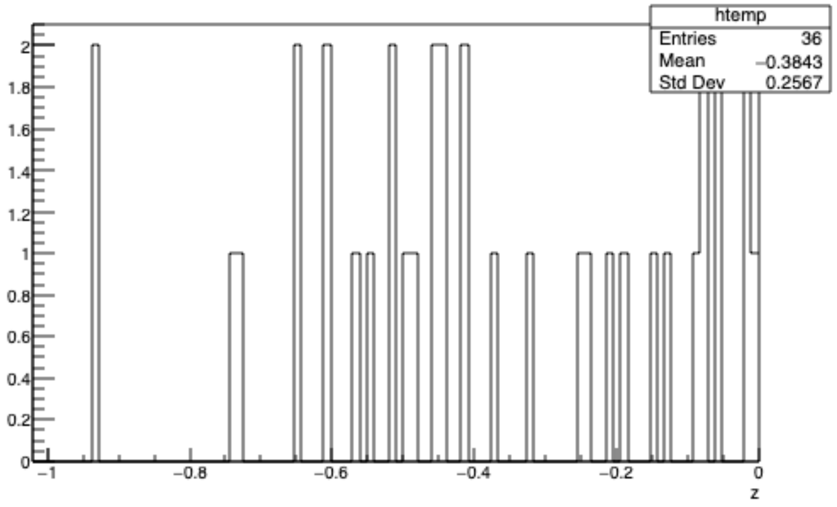


27 MeV/c

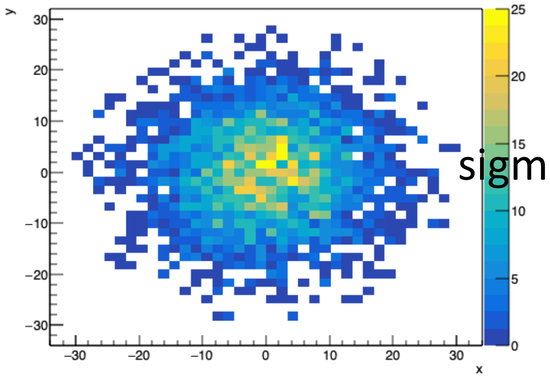


Most muons stopped near the downstream surface

28 MeV/c



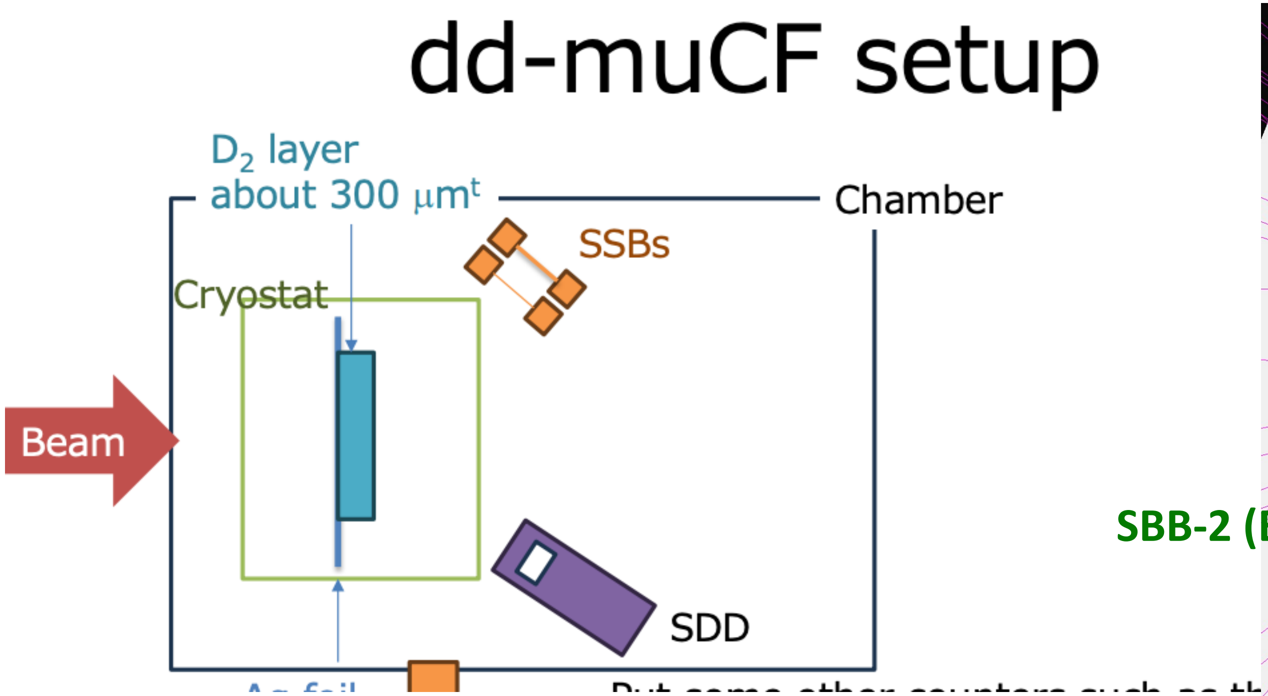
29 MeV/c

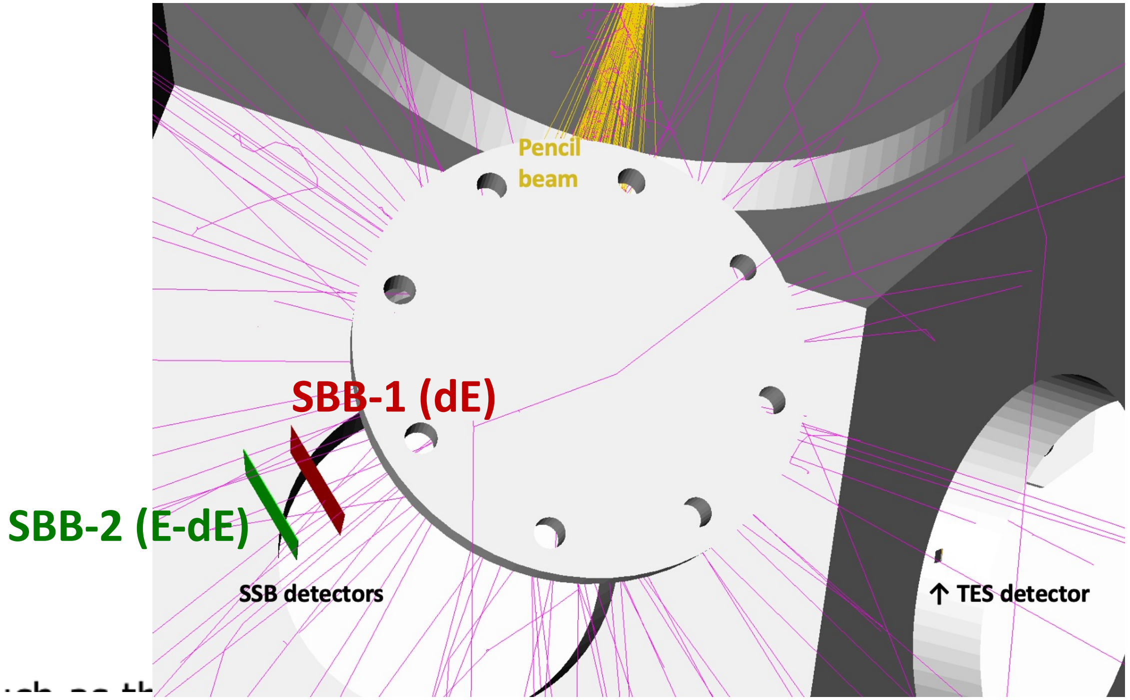


sigma_x/y ~ 9 mm

SSB detectors

- We further model SSB1 detectors as simple silicon slabs (*sensitive det* at Geant4) with single active Si only. For simplification, no dead layers., supporting structures, etc.

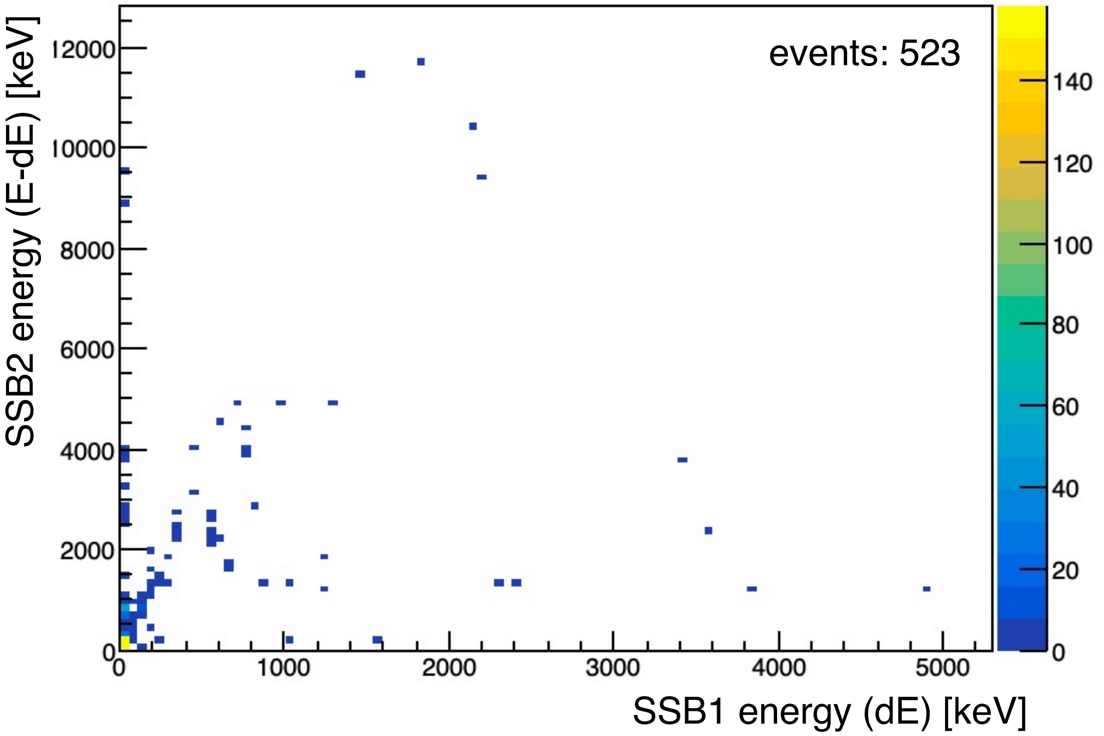




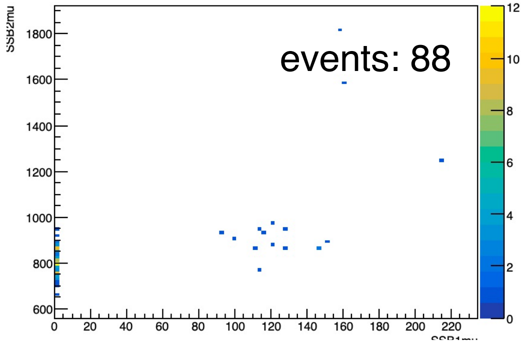
SSB detectors

(dE, E) distribution w/ 28 MeV/c pencil muon beam

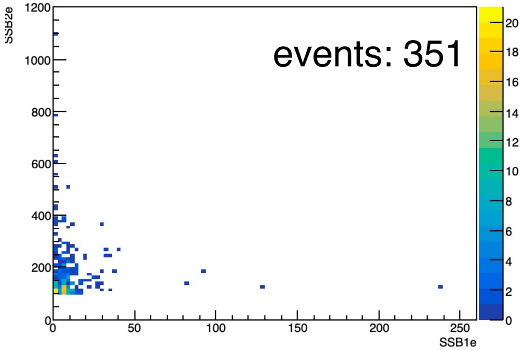
SSB distributions, all particles (SSB2 >100 keV)



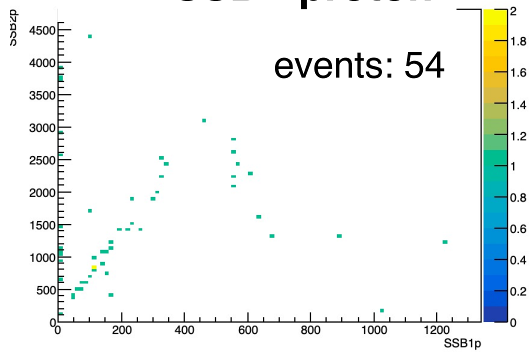
SSB - muon



SSB - electron



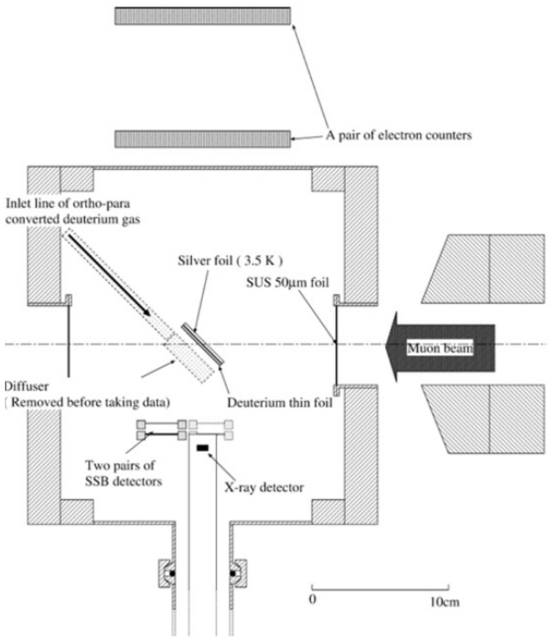
SSB - proton



SSB detectors

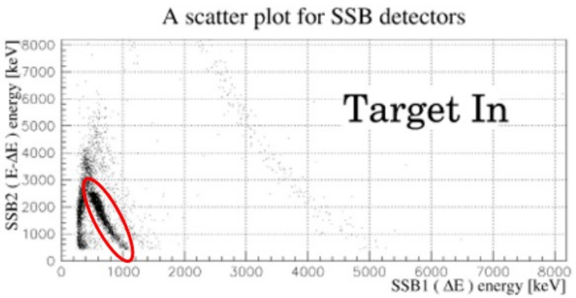
- No proton has been generated or produced on purpose (from MCF).
- Todo: plan to simulate proton (e.g. uniform distribution) inside the D2/T2 target

Toyoda-exp.



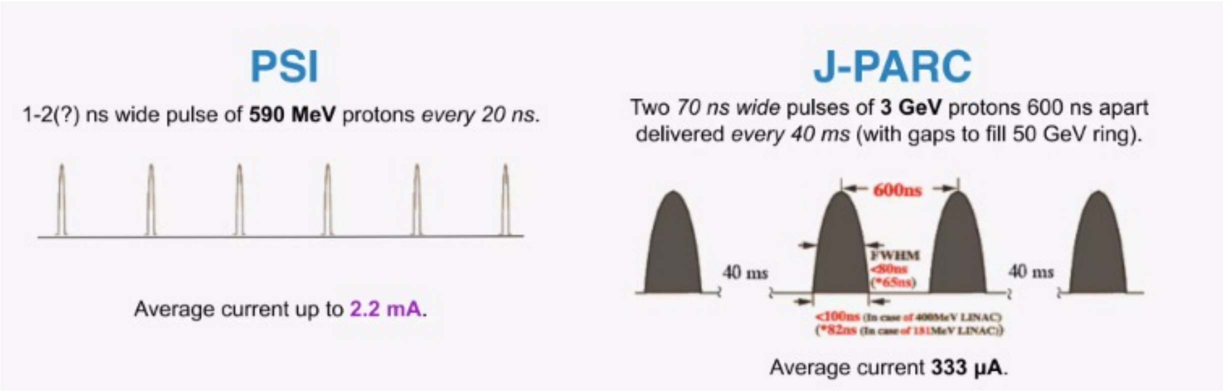
- Scintillators for mue decay electron
- Si(Li) for X-ray
- SSBs for charged particles(dE,E)

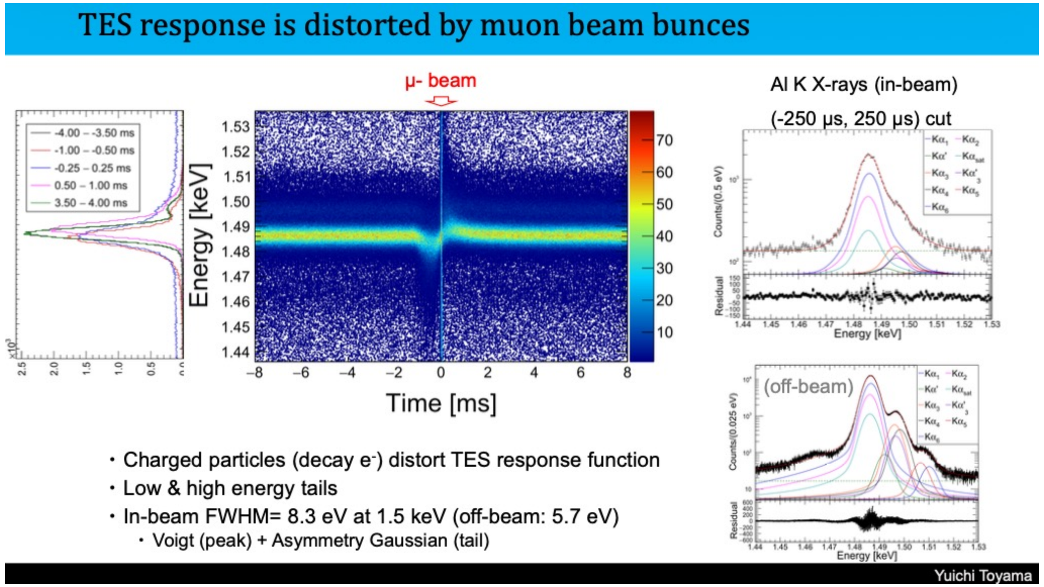
Result @ RAL



Background study on T2 target

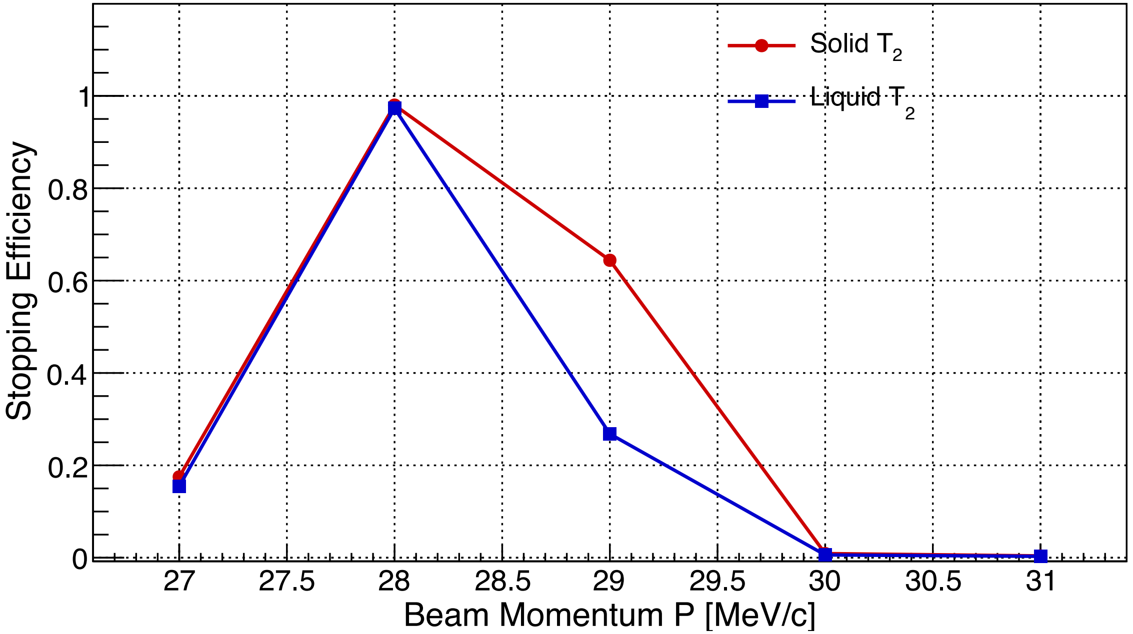
- For future TES X-ray spectroscopy experiments using a T2 (tritium) target, we need to evaluate the advantages and disadvantages of using a pulsed beam (J-PARC) vs a CW beam (PSI).
  - Pulsed beam would be advantageous for avoiding random noise caused by the beta decay;
  - But past TES experiments at J-PARC have shown that background events are quite severe.



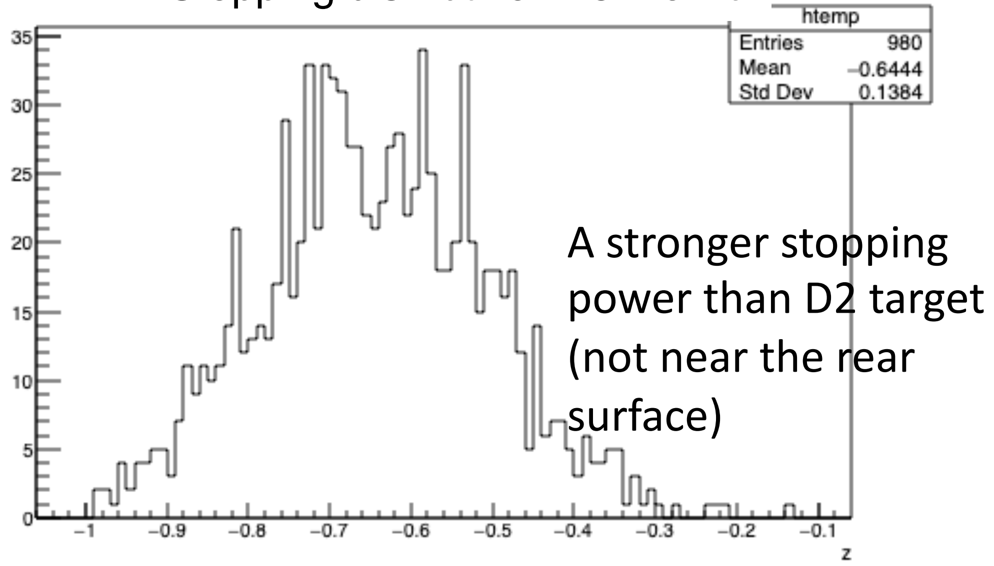


Stopping simulation for T2 target

- As first step, we check again the stopping efficiency for the T2 target.
- It is broader than that for the D2 target, showing a more gradual decline.
- The peaking momentum is 28-29 MeV/c with ~100% efficiency (pencil beam).

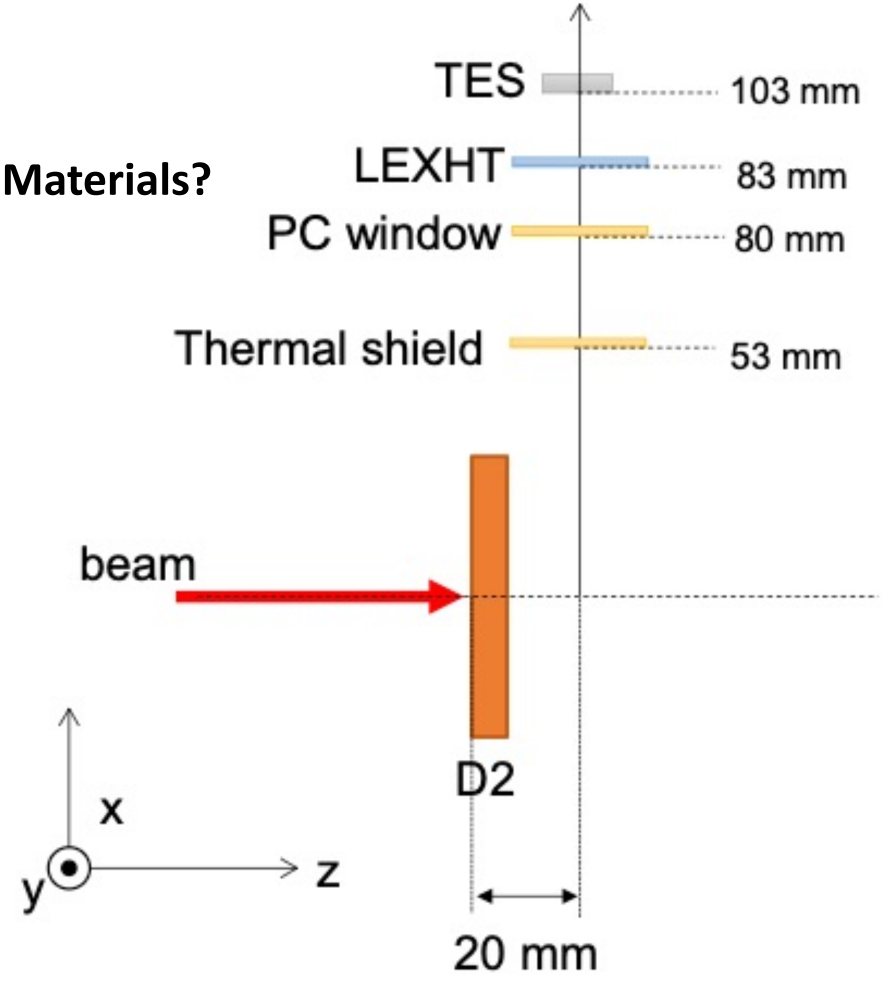


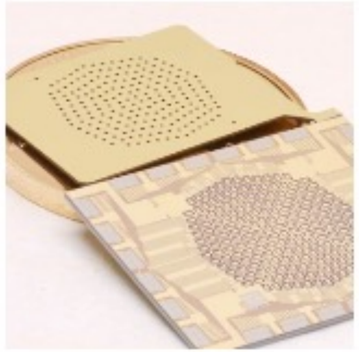
Stopping distribution 28 MeV/c



TES Geometry

Materials?

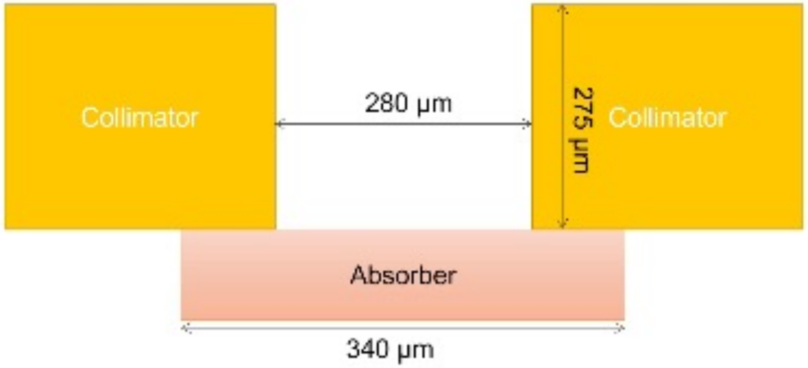




TES
for Low energy X-ray

Absorber: Au (965 nm)
Num. of pixels: 192

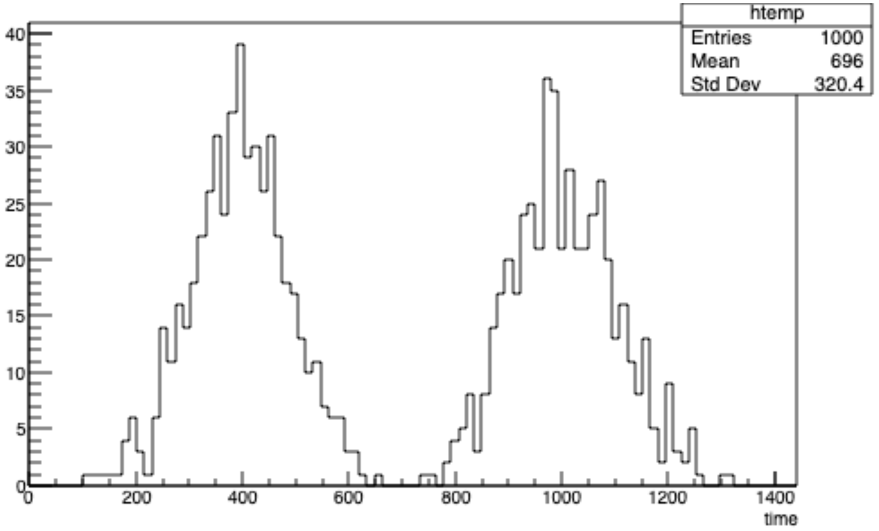
□Effective area 0.1 mm^2/pixel
Multi-pixelization to ~15 mm^2 (TDM readout)



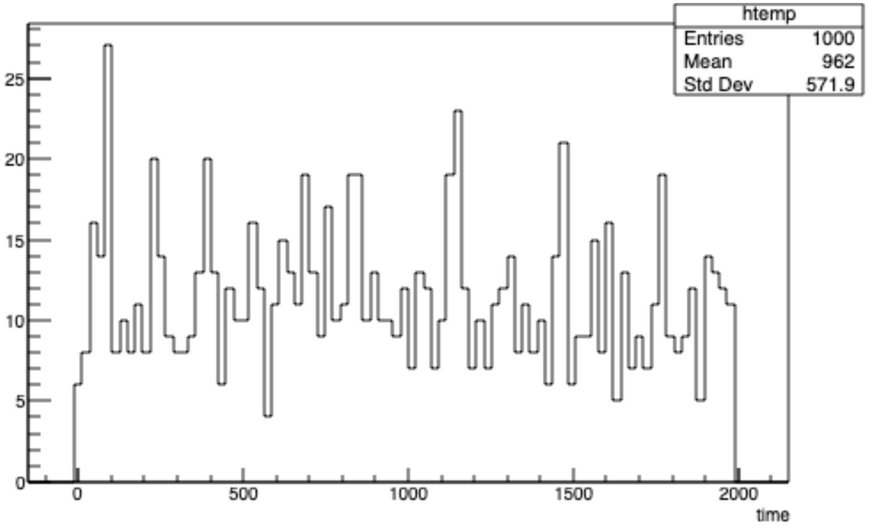
- absorber 340x340 μm
- collimator aperture: 280x280 μm
- collimator thickness: 275 μm (?)

Pulsed beam vs CW beam

- Two different time structures have been created



Pulsed beam



CW beam

- due to very small detection area, large statistics are needed for TES. Simulation is ongoing for this.

Summary

- Decay muon **stopping simulation** was performed with a **full Geant4 model**. We found:
    - The current target size may not fully cover the finite beam (with reasonble parameters);
    - The optimized muon momentum ~28 MeV/c.
- We started implementing **SSB detectors**, checking preliminarily the dE-E scatterting plot with muon, electron proton identified (but not from MCF yet).
- We have also started studying **background for future T2 experiment**. The first step is to compare the CW/pulsed beam. Hopefully the conclusion will be available soon for critical decisions.
- Thank you.

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