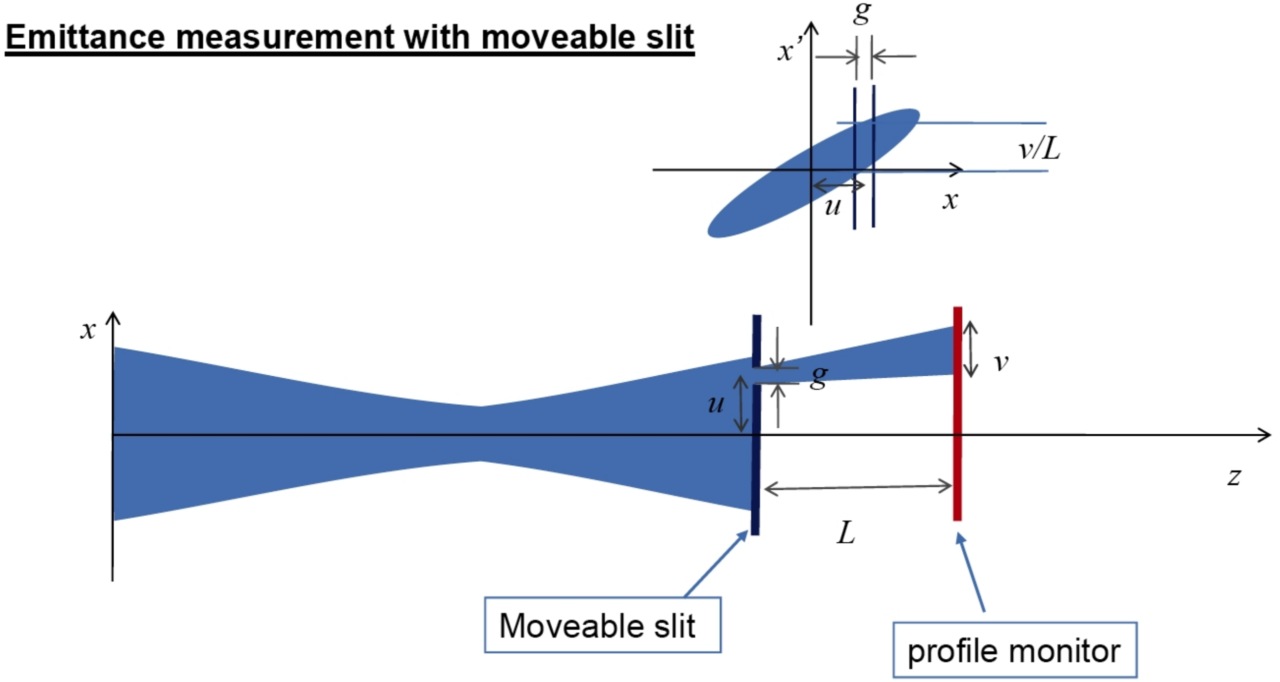
Emittance measurement with a Slit & Grid system in high intensity hadron machine

DITANET-High Intensity Proton Beam Diagnostics workshop
Massy-Palaiseau September 26th-27th

Outline

- Emittance measurement with a Slit & Grid System
- Thermal load
- Space Charge effect
- Multiple Scattering effect

Slit & Grid system



- A slit is used to sample the beam
- Profile monitor for beamlet profile reconstruction

Issue on the slit design and emittance reconstruction

- The slit == beam dump
  - High thermal load and high thermo-mechanical stresses

- The slit geometry and the global emittance meter design has an influence on the measurement resolution
  - Multiple scattering effect on slit edges
  - Space charge effect on the beamlet

LINAC4 emittance meter

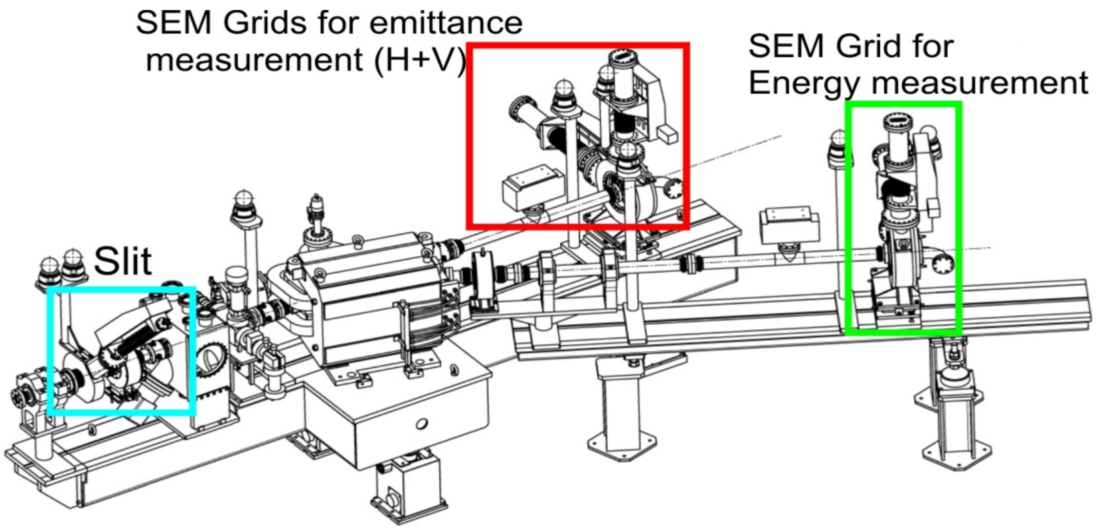


Diagram of the LINAC4 diagnostic test bench

- Will be installed in LINAC4 diagnostic test bench for commissioning phase
  - 3 commissioning stages
    - RFQ exit (3 MeV)
    - End of Chopper line (or MEBT) (3 MeV)
    - Exit of DTL tank 1 (12 MeV)

  - Drift space between slit and grid equal to 3,5 meters

Thermal load-LINAC4 example

Commissioning stage	Energy [MeV]	Intensity [mA]	Pulse Lendth [µs]	σ_x [mm]	σ_y [mm]
MEBT	3	65	100	3.64	3.61
DTL	12	65	100	1.21	1.8

- 4 x10^{13} particles per pulse
- @ 3MeV:
  - Energy => 31 J.cm^{-2}
  - Power (over pulse) => 0.31 MW.cm^{-2}
- @ 12 MeV:
  - Energy => 756 J.cm^{-2}
  - Power (over pulse) => 7.56 MW.cm^{-2}

Thermal load

The Material and geometry should be defined to reduce the thermal load and Mechanical stresses.

Energy deposition has been calculated with FLUKA

First estimation of the temperature with analytical model for the material choice and slit geometry

Energy deposition map from FLUKA used as input in ANSYS analysis

- Material suitable for the slit:
  - Material with high Melting point (Tungsten, Tantalum, Graphite)
  - Material with high Cp (Graphite, Beryllium)
  - Material with High thermal conductivity (Copper)
- Geometry:
  - Spread the energy deposition in a larger surface.

Thermal load-Material of the slit

- For the largest beam power 12 MeV, 65 mA and 100 µs and a given slit geometry (slit at 30° w.r.t. the beam axis):

Material	T surf [K]	T max [K]	Bragg peak depth [µm]	Density [g/cm^3]
Beryllium	907	2148	537	1.85
Graphite	1327	3143	513	1.90
Copper	3091	7028	147	8.96
Tantalum	4076	5368	103	16.65
Tungsten	5660	7028	92	19.35

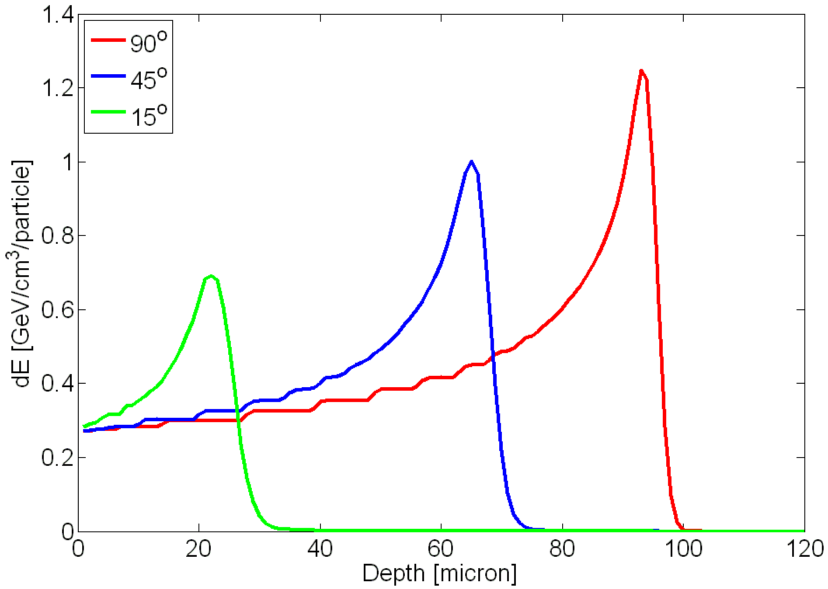
High density material not adapted despite their high melting point (Cu, W, Ta)

The slit material must have a low density, high Cp and high melting point

→ **Graphite is the best candidate**

Thermal load-slit geometry

- The slit is tilted to spread the energy deposition on a largest surface.
- The angle w.r.t the beam axis is chosen in order to keep the thermal load below the Graphite limits.



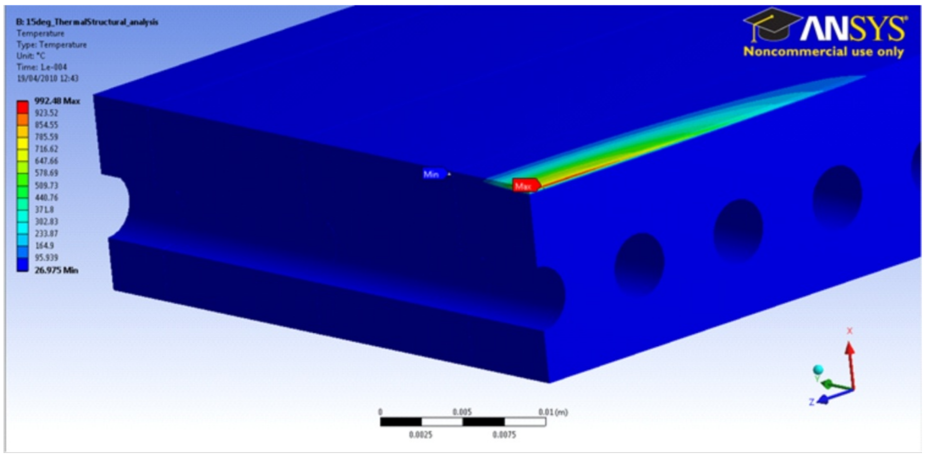
Energy deposition along the z axis for three slit angles at 3 MeV(MEBT), in case of a Graphite slit.

	SRIM	FLUKA		
Angle [deg]	90	90	**45**	**15**
MEBT	2673	2613	2065	1696
DTL	4669	4594	3931	2790

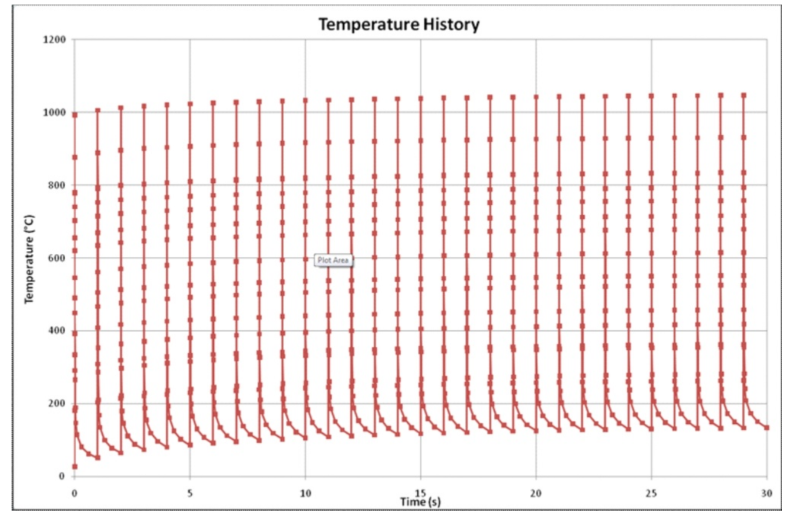
Maximum in temperature for the three commissioning stages, as estimated by analytical model (SRIM) and numerical simulations (FLUKA) when considering a 65 mA, 100 s pulse.

Even with 15°, thermal load is too high for DTL case.
Move the slit 1 m downstream beam sizes increase by a factor 1.5 Temperature drops to 1520 K

Thermal load-ANSYS*



Temperature increases on Graphite plate with cooling circuit in Copper for DTL case. (Courtesy of A. Dallocchio and F. Carra).



Evolution of the temperature with external cooling on Graphite plate at 12 MeV. (Courtesy of A. Dallocchio and F. Carra).

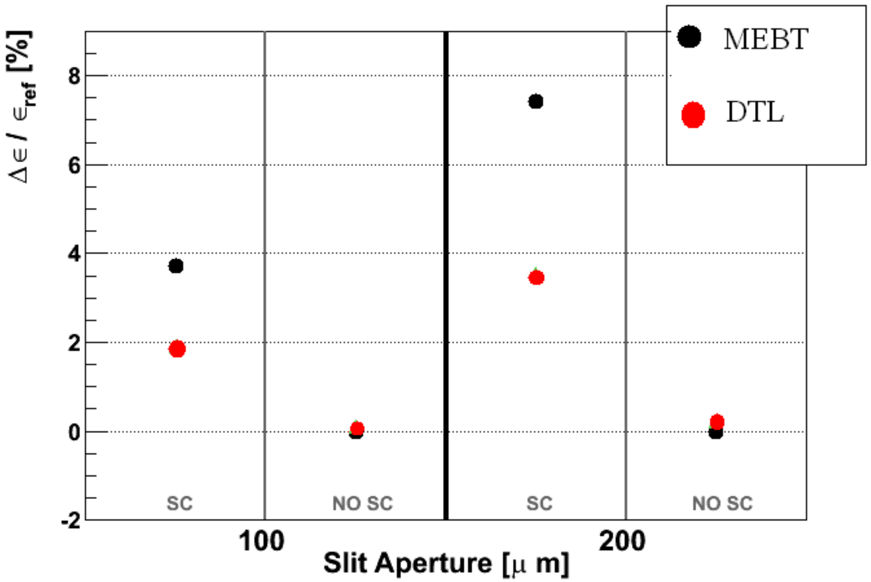
Cooling by conduction and effect of cooling system implemented in ANSYS.

- Maximum temperature reduced by 250 K in 100 μs
- Equilibrium reached after few pulses, T_{max} = 1400-1500 K

*Simulations done by CERN EN group.

Space charge effect on emittance reconstruction

- Full emittance scan simulated with PATH
  - Gaussian beam generated with the expected Twiss parameters
  - Particles tracking with and without space charge effect
  - Two slit aperture simulated (100 and 200 μm)



Emittance reconstruction error due to space charge, considering two slit apertures

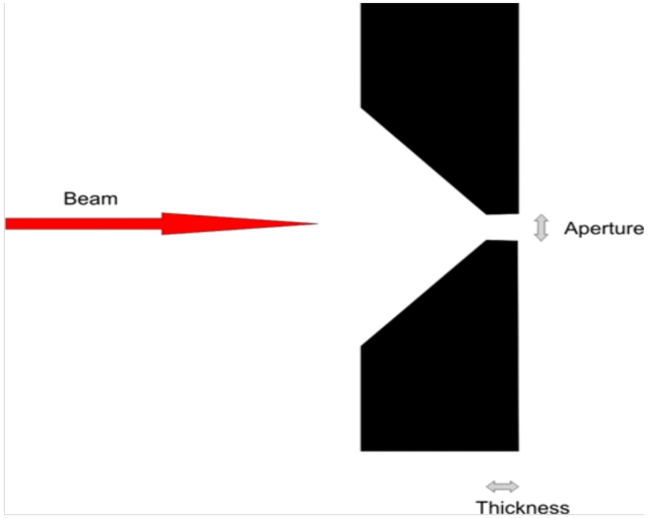
The error increase with the slit aperture

Error vanishes at high energy

Error below 4% with 100 μm slit aperture

Multiple scattering effect

- Effect of the slit geometry on the amount of scattered particles estimated with FLUKA



Schematic diagram of the slit used in the simulations.

Simulation parameters:

- 2,5 MeV proton beam
- Gaussian beam source generated with PATH
- Graphite as slit material (penetration depth 75µm)

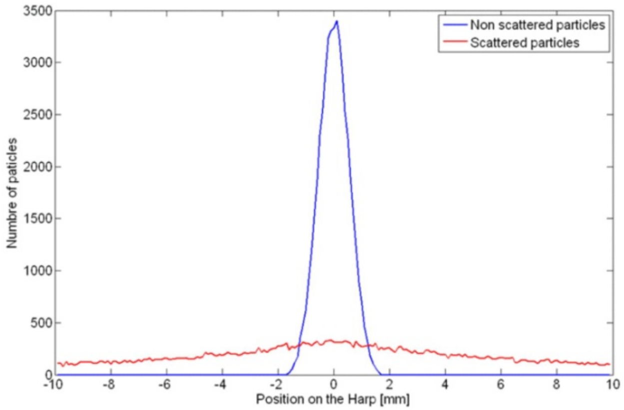
- 3 slit thicknesses simulated (0, 50 and 100 µm)
- 2 slit apertures simulated (100 and 200 µm)

Scattered and non scattered particles position scored on a screen 35,2 cm downstream the slit.

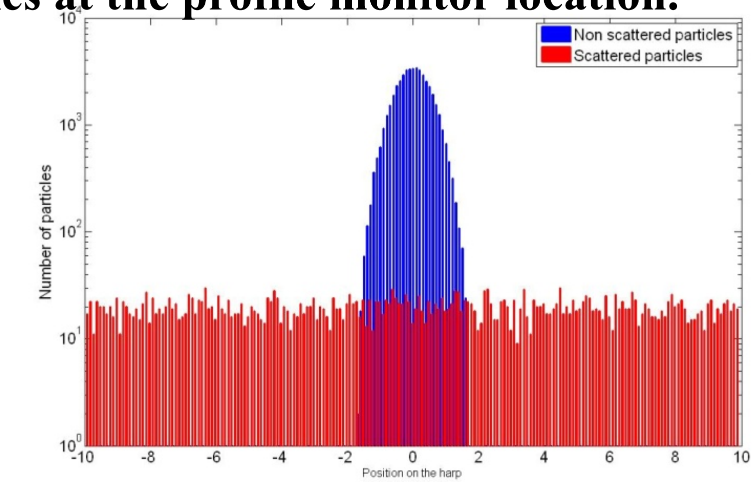
→ Beamlet profile reconstruction

Effect of the slit thickness

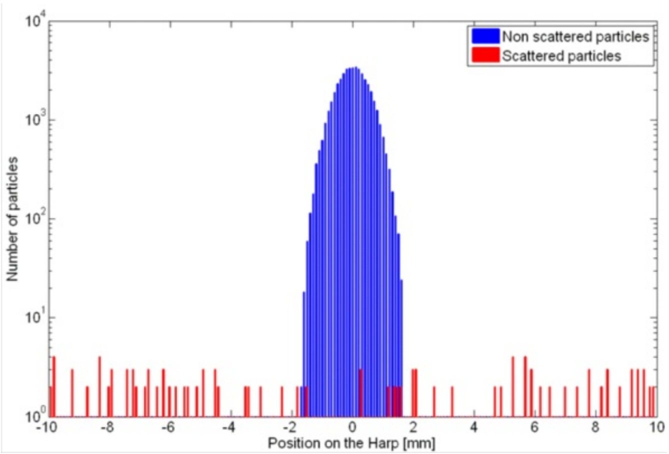
Simulated distribution of the particles at the profile monitor location.



Slit thickness = 0 µm



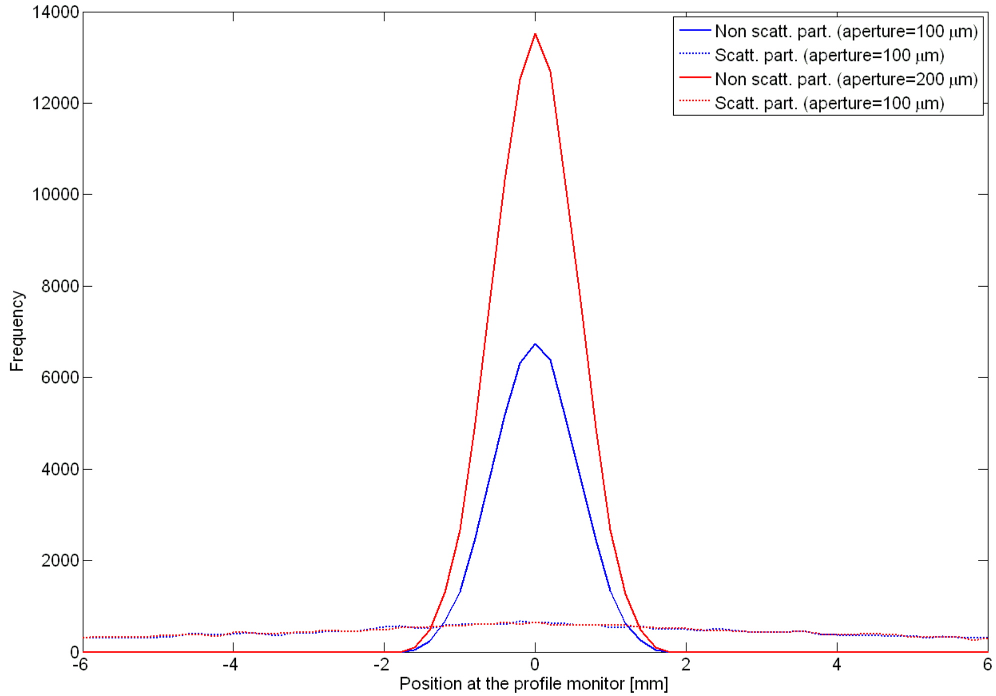
Slit thickness = 50 µm



Slit thickness = 100 µm

- Amount of scattered particles decrease when the slit thickness increase
- Slit thickness must be larger the range of the beam on the slit material

Effect of the aperture



- Amount of scattered particles almost independent of the slit aperture
- Large slit apertures provide better non scattered/ scattered particles ratio

Summary

- Thermal analysis
  - Graphite is the best material choice
  - Slit angle of 15°
  - From ANSYS the maximum temperature is about 1400 K

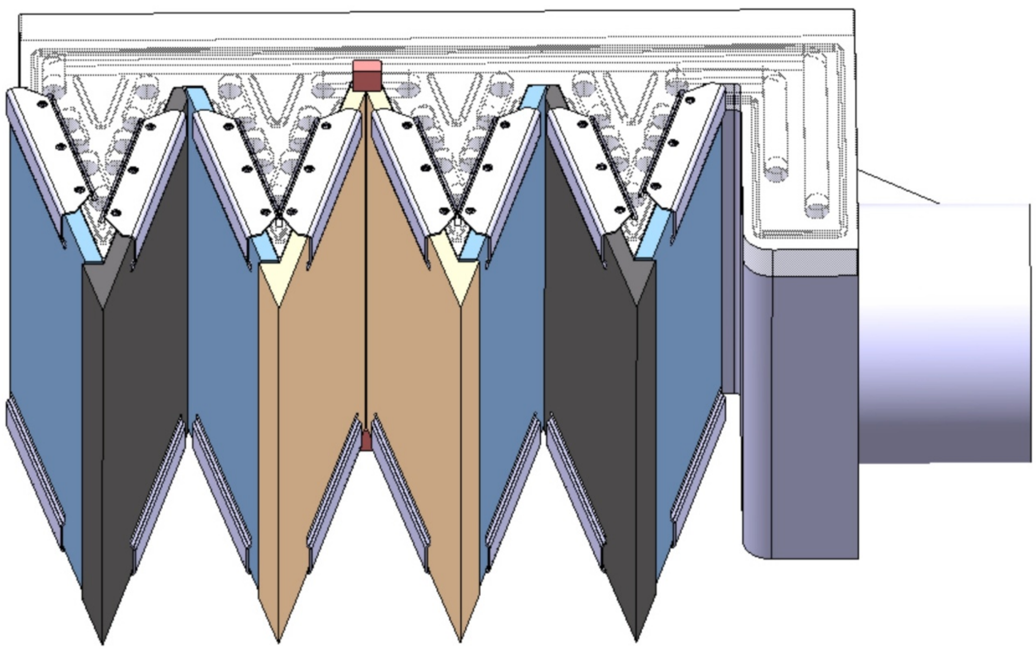
→ Mechanical limit of graphite reached

- Error on emittance reconstruction
  - Space charge => small slit aperture
  - Multiple scattering => large slit thickness and large slit aperture

→ Effect of scattering can be reduced in offline analysis
=> Small aperture to keep error less than few %

Outlook-L4 design

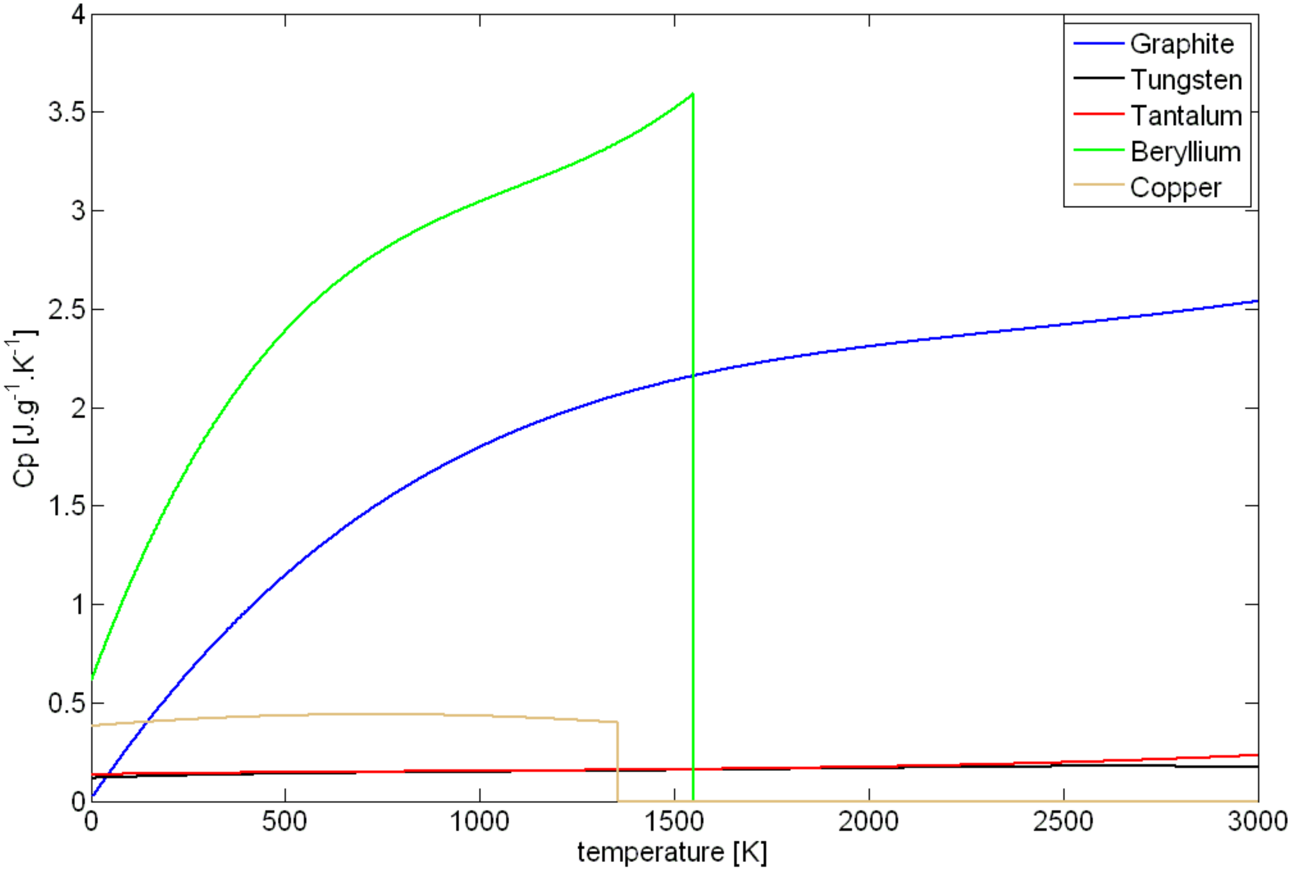
Slit design also influenced by other parameters (space available, mechanics….)



- Graphite plates clamped on a copper block
- Slit aperture adjustable at the assembly (100 or 200 µm)
- Slit thickness equal to 3 mm.

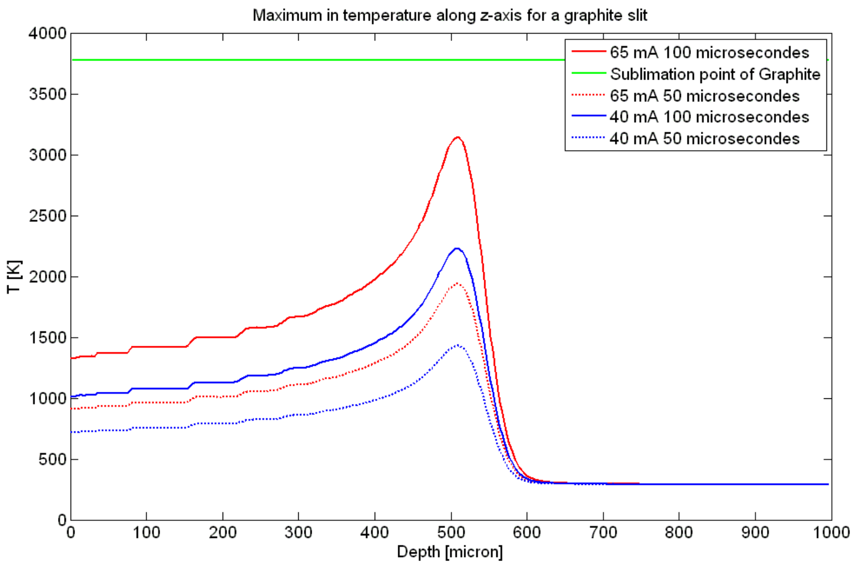
EXTRA SLIDE

Specific heat capacity models :

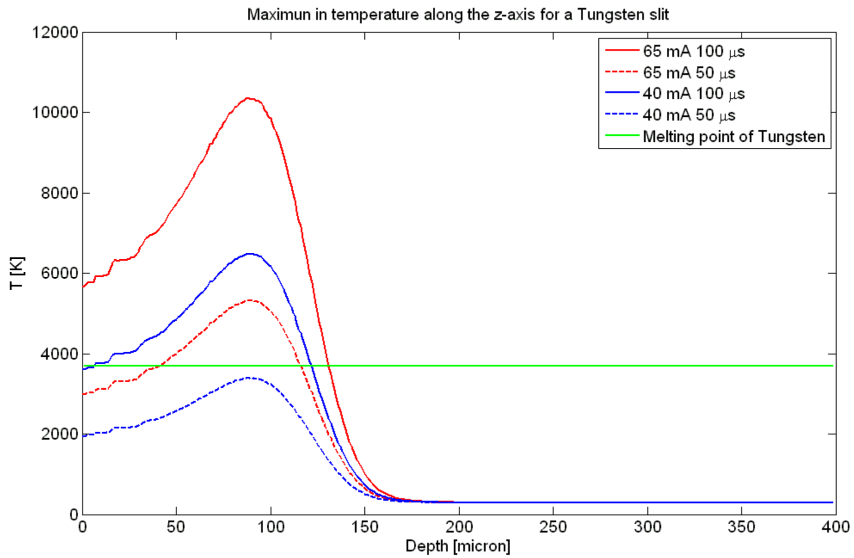


EXTRA SLIDE

Temperature profile along the longitudinal axis, for the DTL case.

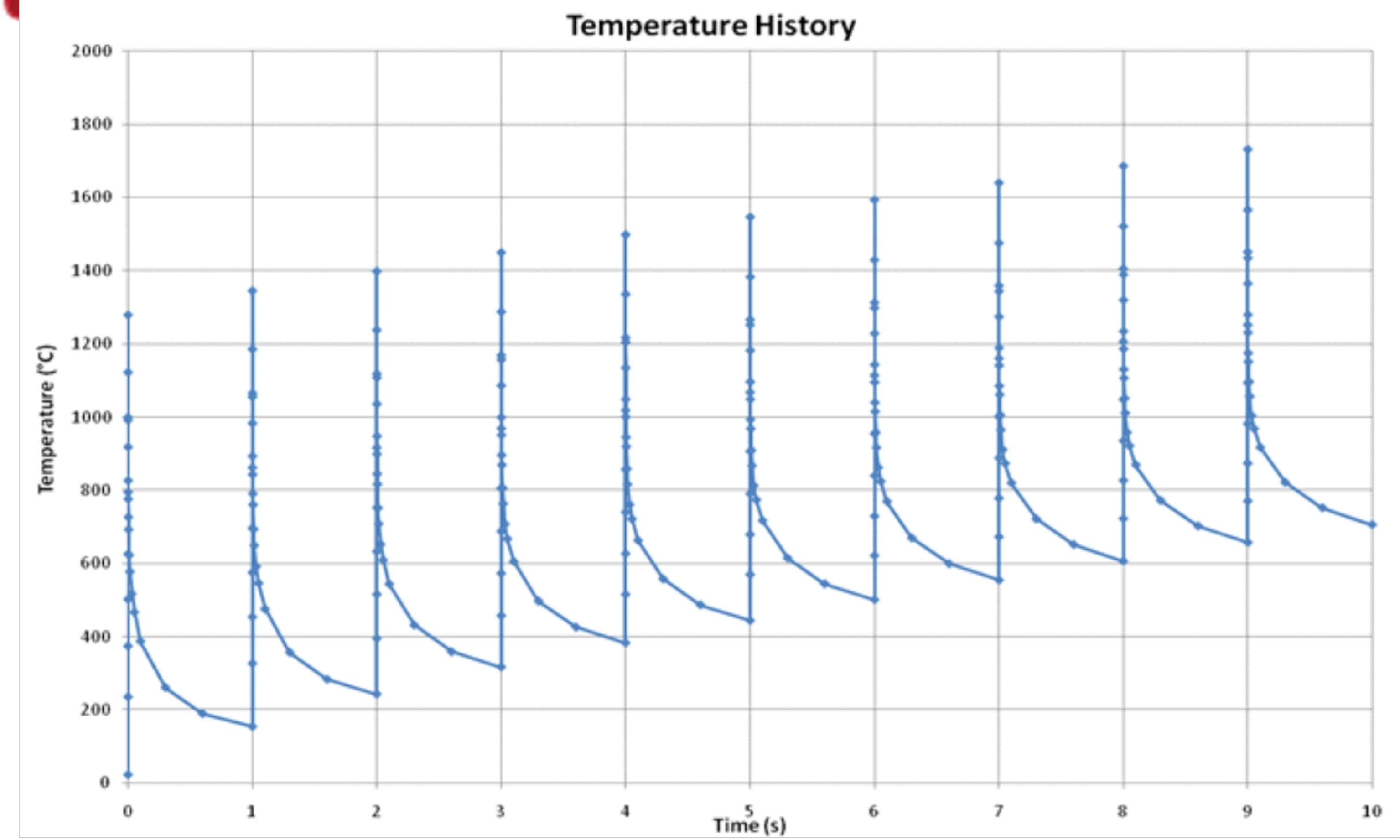


Graphite slit



Tungsten slit

EXTRA SLIDE



Evolution of the temperature with internal cooling by conductivity only, on a Graphite plate at 12 MeV. (Courtesy of A. Dallocchio and F. Carra).

EXTRA SLIDE

- Effect of Multiple scattering on emittance reconstruction assuming the same weight for scattered and non scattered particles.

	Threshold [%]			
	0		1	
Thickness [µm]	ε_{norm} [π.mm.mrad]	Error [%]	ε_{norm} [π.mm.mrad]	Error [%]
0	1.41	516	1.28	467
10	1.41	516	1.28	467
50	0.72	214	0.23	0.62
100	0.31	36	0.22	-0.58
500	0.33	44	0.22	-1.11
PATH	0.23	0	0.23	0