

# Slit & Grid emittance-meter system in high intensity hadron machines

Accelerator Instrumentation and Beam diagnostic  
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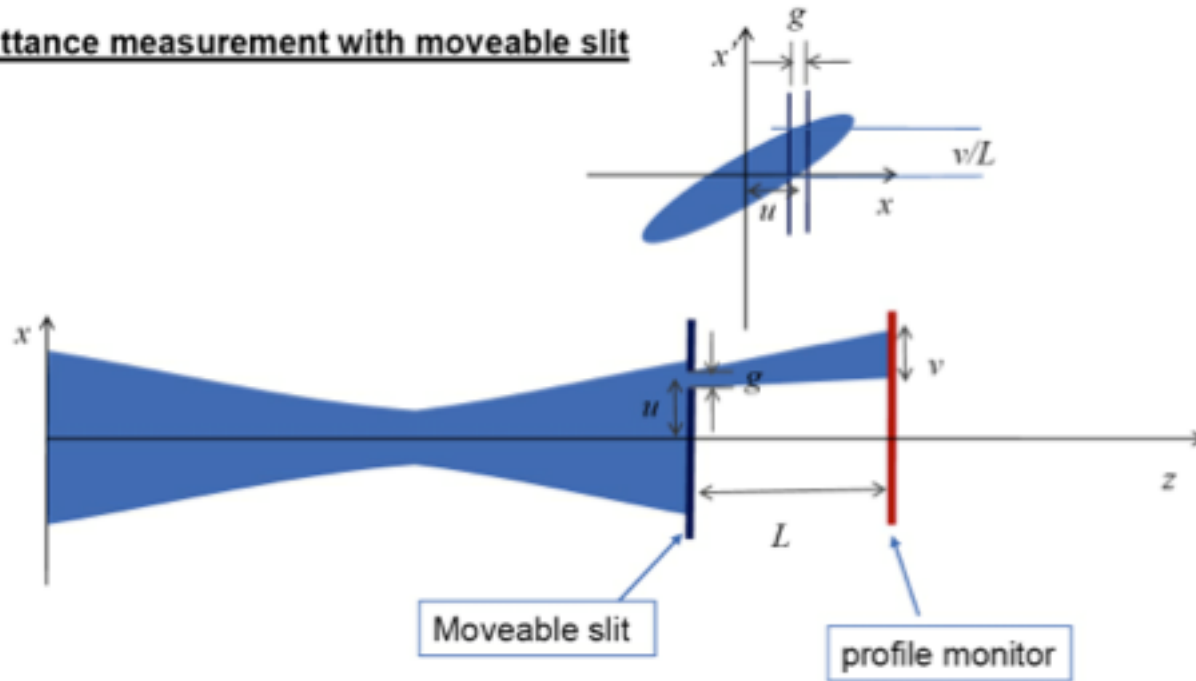


# Outline

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

# Slit & Grid system

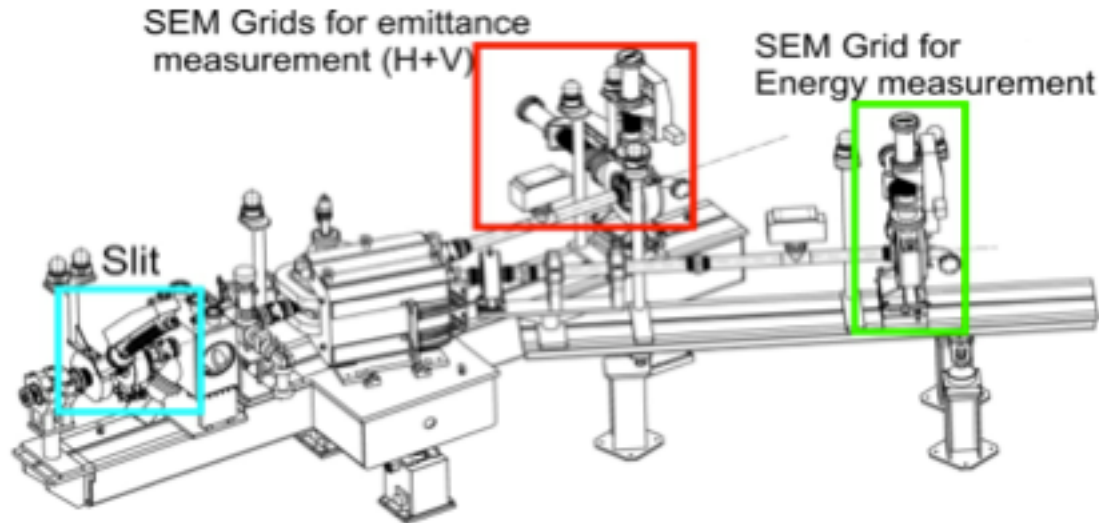
## Emittance measurement with moveable slit



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

# Slit design issues

- 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



**Diagram of the LINAC4 diagnostic test bench**

- Will be installed on the LINAC4 diagnostic test bench
  - 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 Length [ $\mu$ s]	$\sigma_x$ [mm]	$\sigma_y$ [mm]
MEBT	3	65	100	3.64	3.61
DTL	12	65	100	1.21	1.8

- $4 \times 10^{13}$  particles per pulse
- @ 3MeV:
  - Energy  $\Rightarrow$  31 J.cm<sup>-2</sup>
  - Power (over pulse)  $\Rightarrow$  0.31 MW.cm<sup>-2</sup>
- @ 12 MeV:
  - Energy  $\Rightarrow$  756 J.cm<sup>-2</sup>
  - Power (over pulse)  $\Rightarrow$  7.56 MW.cm<sup>-2</sup>

# Thermal load

The material and geometry should be defined to reduce the thermal load and mechanical stresses.

- Expected energy deposition and temperature increase by means of
  - Analytical model
  - Numerical simulations → Energy deposition maps from FLUKA used as input for ANSYS thermo-mechanical studies
- Suitable slit materials:
  - Materials with high Melting point ([Tungsten](#), [Tantalum](#), [Graphite](#))
  - Materials with high Cp ([Graphite](#), [Beryllium](#))
  - Materials with High thermal conductivity ([Copper](#))
- Geometry:
  - Aim at diluting the energy deposition over a larger surface

# Thermal load - Slit material

- For the highest beam power 12 MeV, 65 mA and 100  $\mu$ s and a slit angle of 30° w.r.t. the beam axis:

Material	T surf [K]	T max [K]	Bragg peak depth [ $\mu$ m]	Density [g/cm <sup>3</sup> ]
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

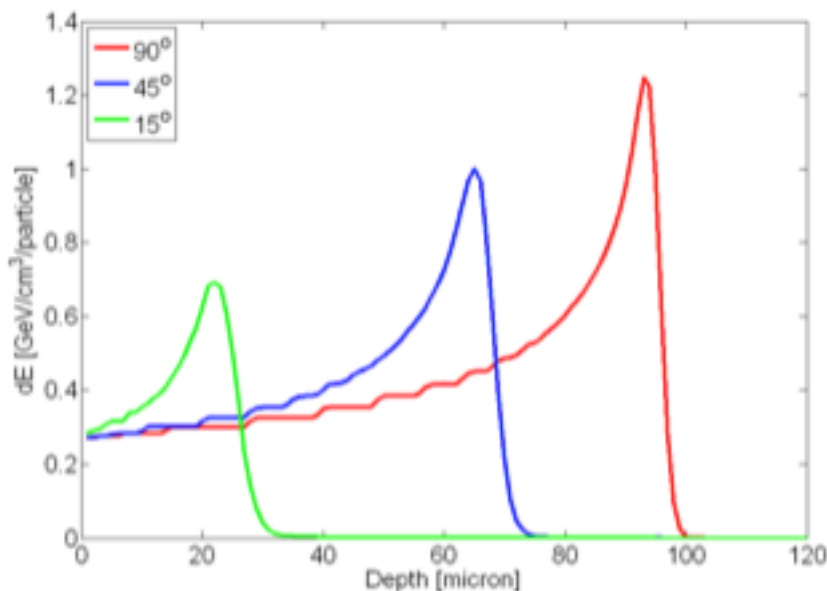


**Graphite is the best candidate**



## Thermal load - slit geometry

- Tilting the slit w.r.t. beam trajectory → energy deposition diluted over a larger 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.

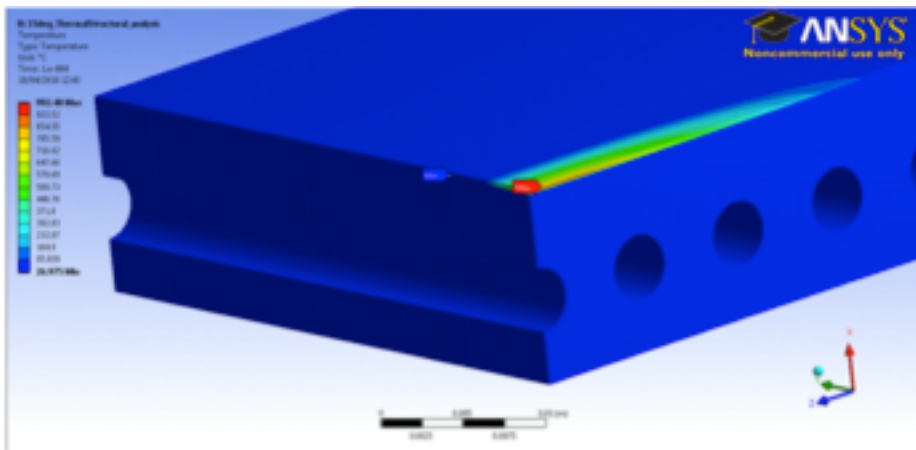
	SRIM		FLUKA	
Angle [deg]	90	90	45	15
<b>MEBT</b>	2673	2613	2065	1696
<b>DTL</b>	4669	4594	3931	2790

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

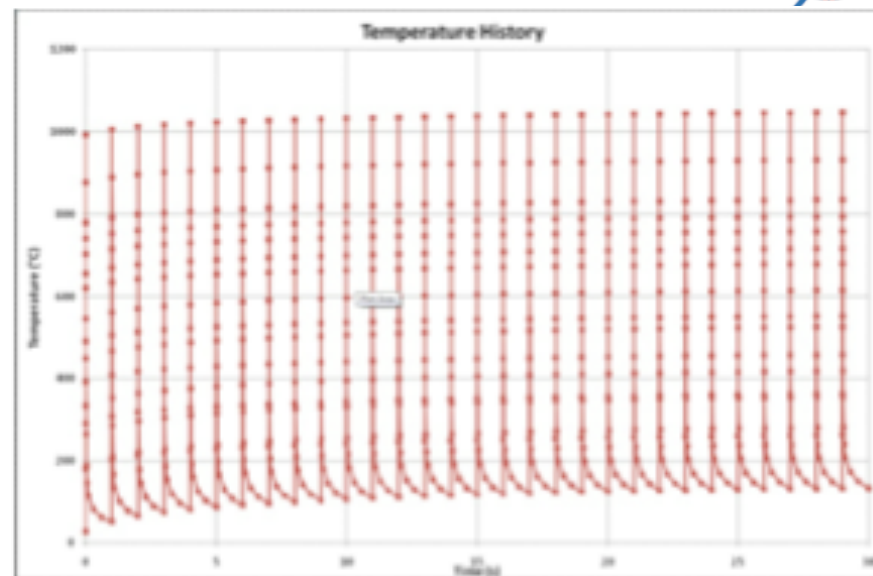
Even with 15°, thermal load is too high for DTL case.

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. Dallochio and F. Carra).



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

Internal cooling by conduction and external cooling system implemented in ANSYS.



- Maximum temperature drops by 250 K in 100  $\mu$ s
- Equilibrium reached after few pulses,  $T_{\max} = 1400-1500$  K

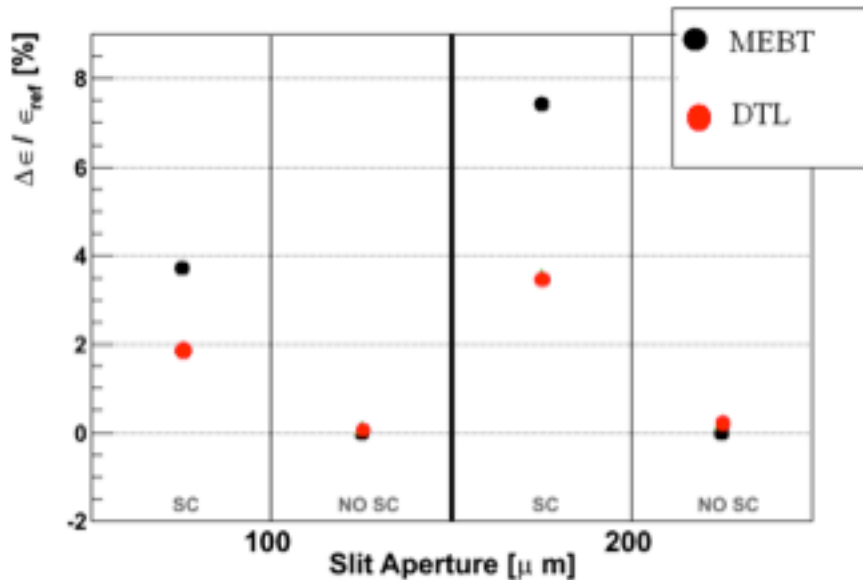
\*Simulations done by CERN EN group.

# L4

# Space charge effect on emittance reconstruction



- Full emittance scan simulated with PATH tracking code
  - Gaussian beam generated with the expected Twiss parameters
  - Particles tracking with and without space charge effect
  - Two slit apertures simulated (100 and 200  $\mu\text{m}$ )



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



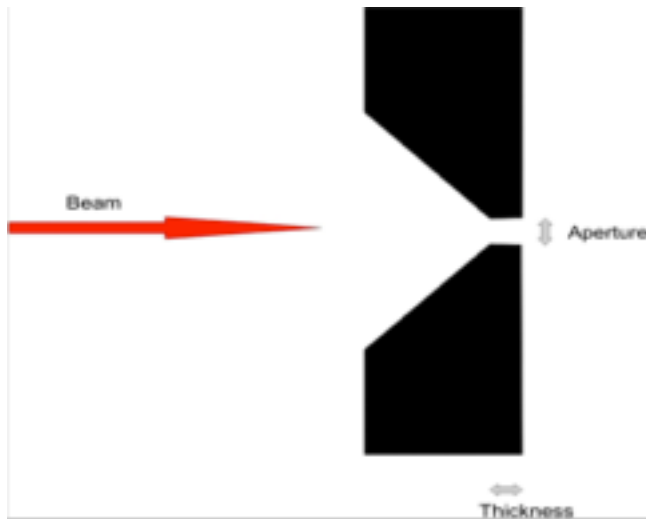
The error increases with the slit aperture

Error vanishes at high energy



Error below 4% with 100  $\mu\text{m}$  slit aperture

- Effect of the slit geometry on the amount of scattered particles estimated with FLUKA (simulations based on SNS emittance meter design).



Simulation parameters:

- 2,5 MeV proton beam
- Gaussian beam source generated with PATH
- Graphite as slit material (penetration depth 75 $\mu$ m)
- 3 slit thicknesses simulated (0, 50 and 100  $\mu$ m)
- 2 slit apertures simulated (100 and 200  $\mu$ m)

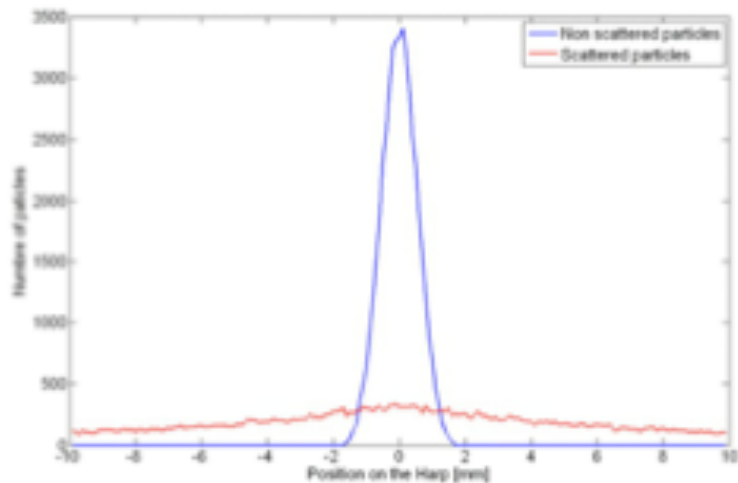
**Schematic diagram of the slit used in the simulations.**

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

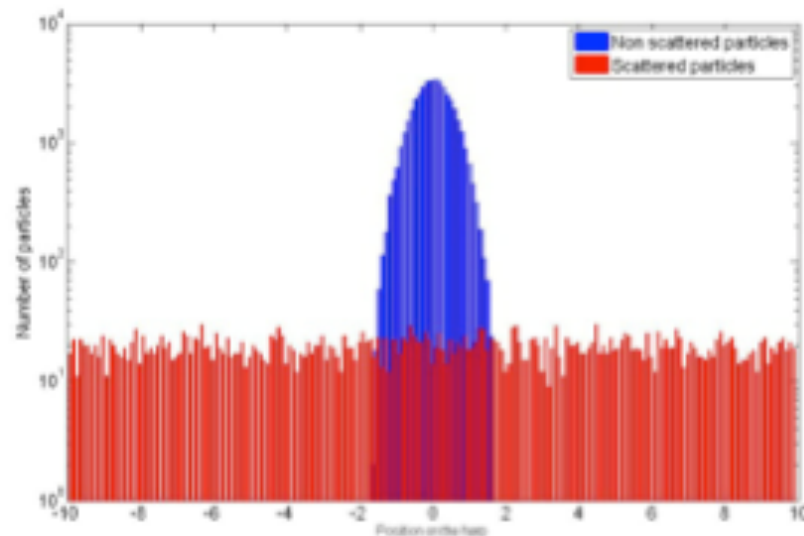


Beamlet profile reconstruction

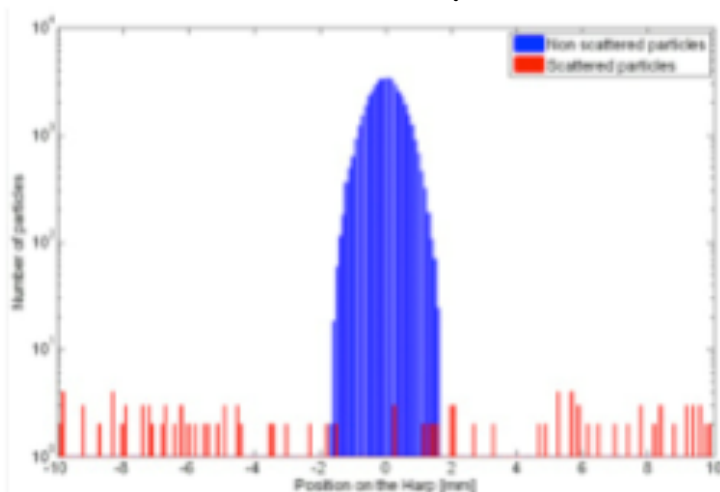
Simulated distribution of the particles at the profile monitor location.



Slit thickness = 0  $\mu\text{m}$



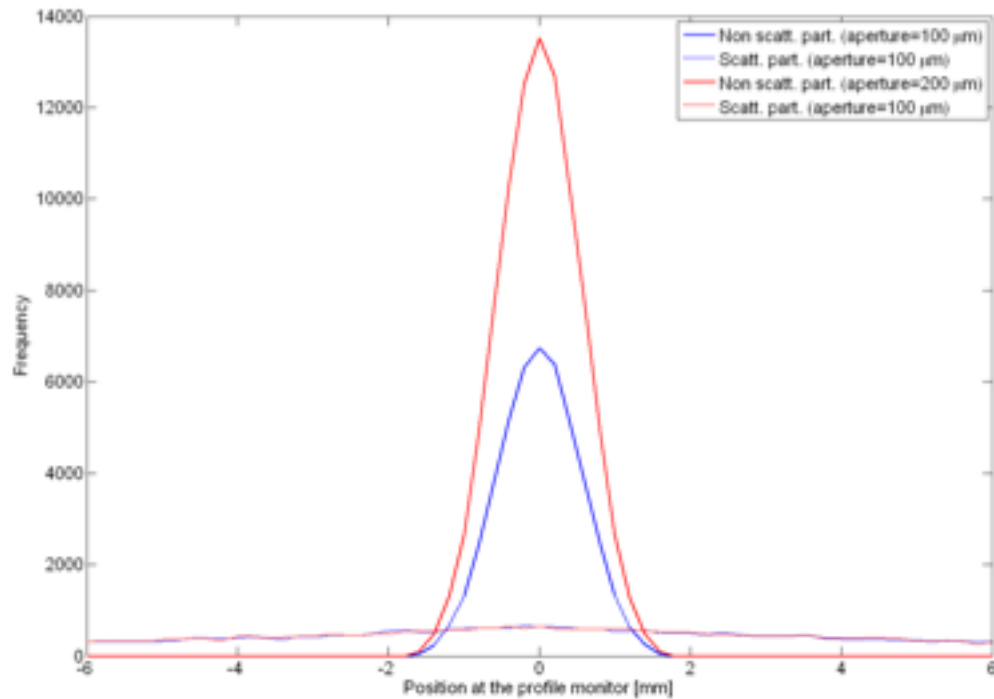
Slit thickness = 50  $\mu\text{m}$



Slit thickness = 100  $\mu\text{m}$

- Amount of scattered particles decrease when the slit thickness increase
- Slit thickness must be larger than 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  $15^\circ$
  - From ANSYS the maximum temperature is about 1400 K



Mechanical limit of graphite reached

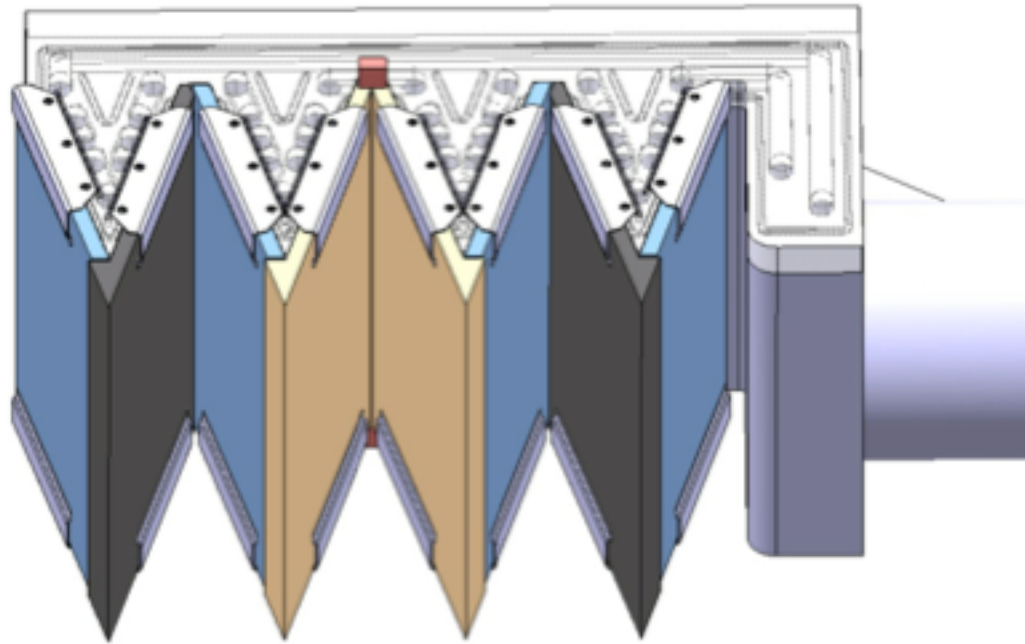
- Error on emittance reconstruction
  - Space charge  $\Rightarrow$  small slit aperture
  - Multiple scattering  $\Rightarrow$  large slit thickness and large slit aperture



Effect of scattering can be reduced with offline analysis  
 $\Rightarrow$  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  $\mu\text{m}$ )
- Slit thickness equal to 1 mm.