TRANSVERSE PHASE SCANNER DEVELOPMENTS AT IPHC

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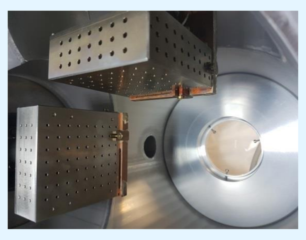
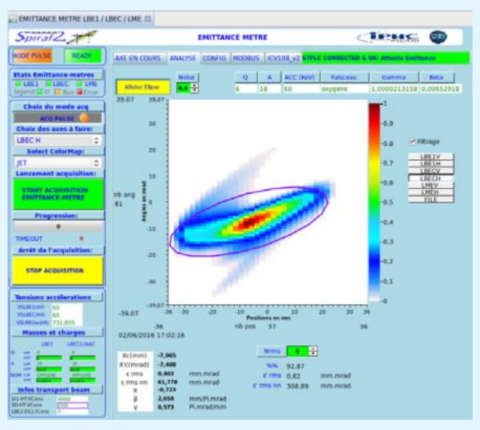
The transverse phase scanner has been initially developed at IPHC in the 2000s for the SPIRAL 2 project then for FAIR with CEA-IRFU. It is a slit-slit system based on Allison principle. Each beamlet sampled by the entrance slit is analysed according to its incidence angle and energy. The analysis is performed by an electrostatic deflector composed of two parallel plates and a simple relation links the applied voltage to the angle. The beamlet current intensity is measured with a Faraday cup located after exit slit.

DESIGN PARAMETERS

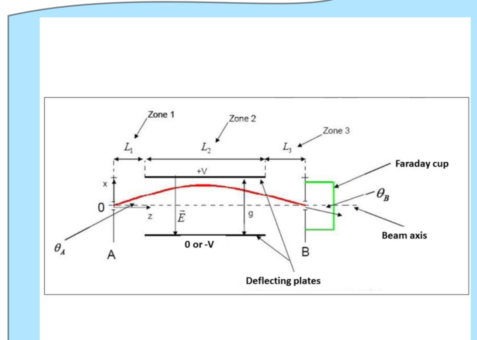
Transverse phase space scanner enables emittance measurement for low energy ion beams. It is a slit-slit system based on Allison principle and has an electrostatic deflector, an electron repeller and a Faraday cup. The electronics and data processing is mainly based on CompactRio and Labview standards



Assembly with dual probes



Transverse beam emittance figure



Probe is sampling beam and producing 120 µm large beamlets. Ions are deviated in an electrostatic deflector according to their energy and incidence angle. The applied voltage corresponds to a particular angle so that ions are collected on a Faraday cup located downstream an exit slit in order to measure the current intensity of the beamlet

Beam analysis based on Allison principle

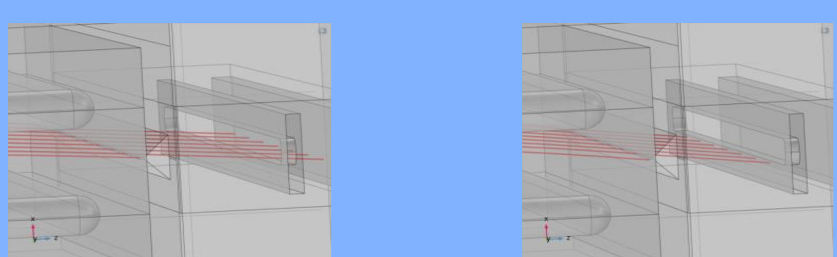
$$\Theta \approx \frac{\Delta V\ L2\ (L2+2L3)}{4\ U\ g\ (L1+L2+L3)}$$

ΔV: Voltage between plates
Θ: initial incidence angle
U: beam acceleration potential
g, $L1$, $L2$, $L3$: dimensions

Scan plane	Horiz. or vertic.
Scan speed	Few min. - few hours
Scan length	≤ 123 mm
Total displacement length	250 mm
Resolution in position	100 µm
Resolution in angle	1 mrad
Angular acceptance	+/- 100 mrad
Current intensity	10-3000 µA
Power CW (DC)	≤ 300 W
Emittance Norm.	0.01-1 π mm.mrad
Beam transverse envelop	≤ 80 mm in diam.
Time structure	DC or pulsed
Electron repeler	1 kV

Main design parameters

Ion beam tracing inside probe



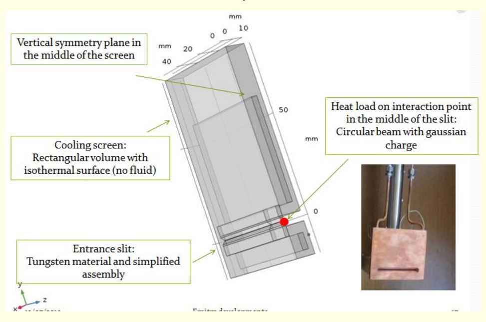
Trajectory of ions without and with losses. Study case : 60 keV beam emission with 80 mrad incidence and ± 760 V deflecting voltage

Due to fringe field and collimation of beam by both slits and electron repeller some losses appear along the trajectory of the ions. According to beam energy and intensity, geometrical, angular and momentum acceptance may be reduced significantly at Faraday cup location depiste being unperturbated at the exit slit.

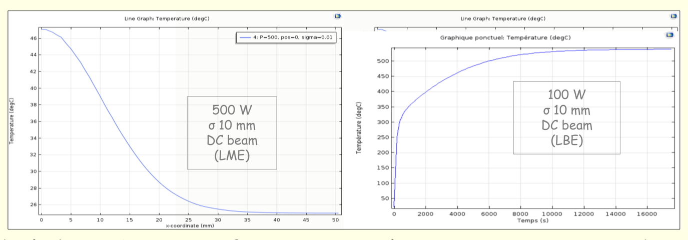
DESIGN STUDIES

Heat load and thermal stress

Entrance of probe is submitted to ion-beam irradiation thus to heat load. Due to power density temperature can reach several 100s Celsius degrees. Model has been defined and numerical simulations performed to characterize the behaviour of the entrance slit during irradiation with a 300 W DC and pulsed beam

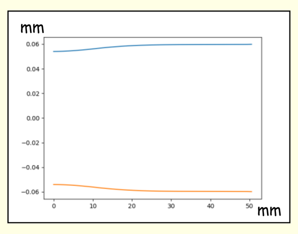


3D model with conduction and radiation heat transfer (vertical symmetry plane in the middle of the slit)

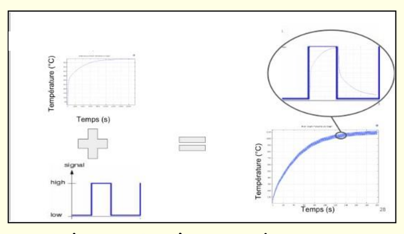


Radial distribution of entrance slit temperature and variation with time (on the edge of the slit)

DC mode	LME configuration				
Beam power (W)	300	300	300	100	100
Sigma (mm)	1	10	50	10	50
Temp. (°C)	727	37	25	26	24
Time 95 % (s)	0.2	0.4	0.7	0.4	0.7
Expansion (%)	6	0	0	0	0
Error (%)	10	10	10	10	10



Slit profile and expansion in the middle of the slit (located on the left). FAIR study case at 100 keV, 100 mA, 4 Hz, 2 %, σ 10 mm



Pulsed regime with typical pseudo-stationnary shape and micro-structure due to dynamic regime

Stopping power at entrance slit

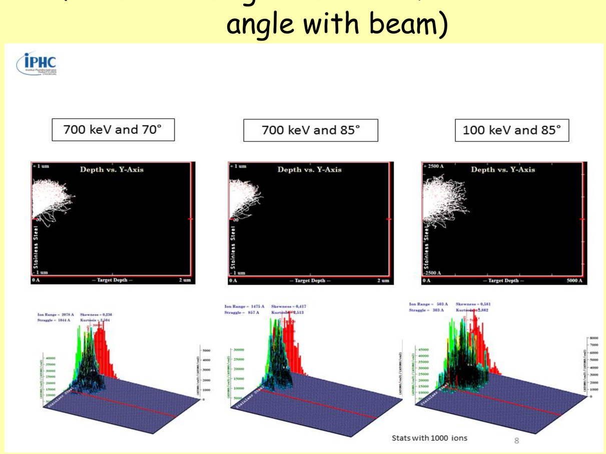
Stopping power is weakest for proton beam : at 100 keV estimated range in tungsten is < 0.5 µm. Slit thickness is ≥ 0.3 mm (trapezoidal shape) and enables an accurate sampling of the beam. Nevertheless perpendicular angle of contact surface doesn't favor heat dissipation thus compromise is necessary to limit backscattering

A ion (amu)	U (kV)	Charge state	Kinetic energy (keV)	Range (µm)	Note
1	100	1	100	0.46	Proton
1	700	1	700	3.85	Proton
14	100	1	100	0.65	Nitrogen 1^+
14	700	1	700	4	Nitrogen 1^+
132	100	1	100	0.13	Xenon 1^+
132	4	25	100	0.13	Xenon 25^+
132	100	25	2500	2.51	Xenon 25^+
238	100	1	100	0.1	Uranium 1^+
238	4	25	100	0.1	Uranium 25^+
238	100	25	2500	1.29	Uranium 25^+
238	100	40	4000	2.08	Uranium 40^+

Ion interaction on tungsten surface with orthogonal incidence

Surface emission and scattering

Surface emission decreases with incident ion energy and increases with atomic number. Scattering and sputtering increase with small incidence angle. With angle < 85° surface emission is strongly reduced. Angular distribution is a relevant criteria of the slit design and contaminants reduction (due to contact angle with beam)



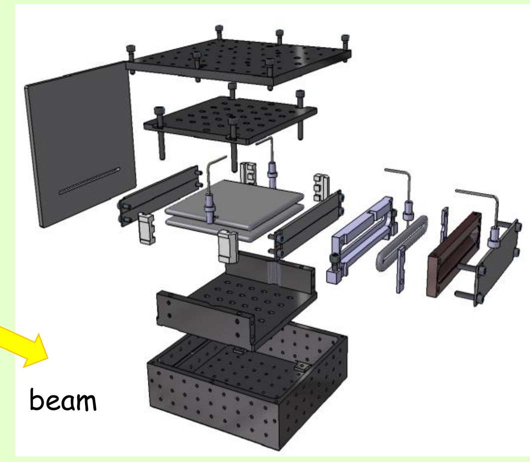
Ion energy (keV)	700	700	100
Angle (°)	70	85°	85°
Range (µm)	0.21	0.15	0.05
Backscattering (ion/1000) Angle (°)	100 ~ 10-120	486	610
Sputtering (atom/ion) Angle (°)	Cr 0.1041 Fe 0.7828 Ni 0.1922 ~ 20-160	Cr 0.3824 Fe 3.57 Ni 0.8779 ~ 20-150	Cr 0.7327 Fe 6.24 Ni 1.53 ~ 10-160

Incident nitrogen ions on stainless steel surface at 100 and 700 keV

EXPERIMENTATION

Experimental program

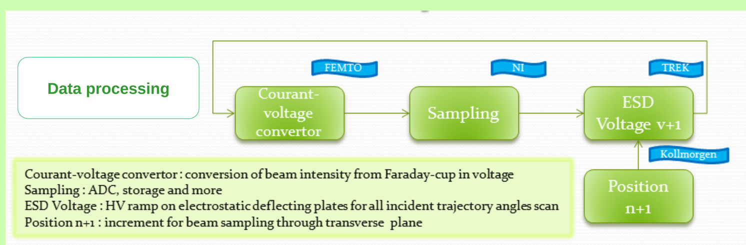
The program concerns the validation of the thermal calculations and validation of model. A substantial amount of heat should be deposited of the entrance slit (300 W) with accurate alignement of beam on slit and positioning of mechanical parts. Deposited power range varies bewteen 10 and 300 W in order to measure different temperatures. Beam spot radius varies between 1 and about 50 mm in order to control the power density (the setting of the beam duty cycle is another option)



Detailed view of different parts of probe. Heat will be deposited on entrance slit and transfered by conduction and radiation to cooling screen and other parts

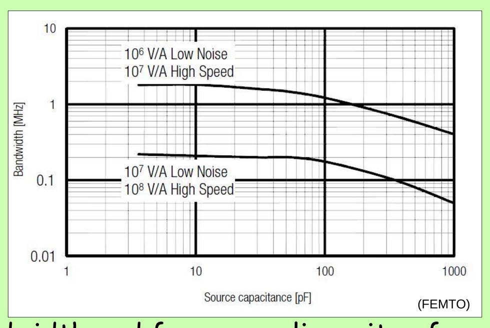
Cooling screen with entrance slit, water circuit and feedtroughs

Front-end electronics and current-voltage convertor



Parameter	Value	Note
Convertor BW	1,2-30 MHz	With 100 pF at low and high current
Sampling $t_{sampling}$	4.4 µs	Mainly acquisition card (ADC)
Brushless motor $t_{position/step}$	10 ms/0.1 mm	
ESD Voltage $t_{voltage\ step}$	2 ms	Slew rate 370 V/µs + RC circuit time constant

+ buffer for pulse/pulse storage and offline computing (access to semi-dynamical emittance measurement)

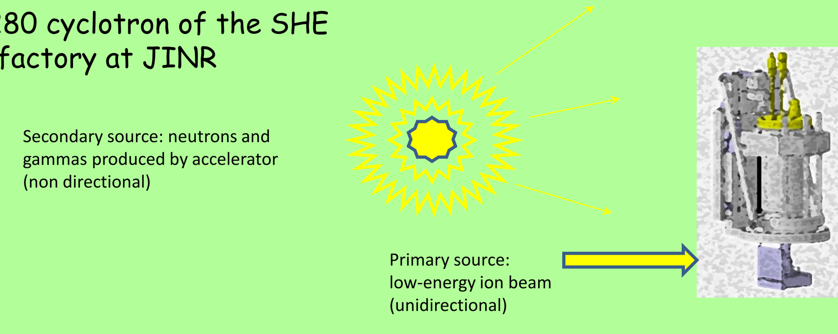


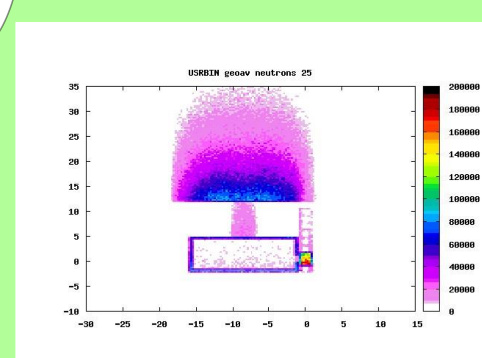
Measurement of bandwidth and frequency linearity of current-voltage convertor. Specific case for low current < 50 nA. BW increases with intensity and decreases with charge capacitance (~ 100 pF for real case with coax cable)

Campain with beam

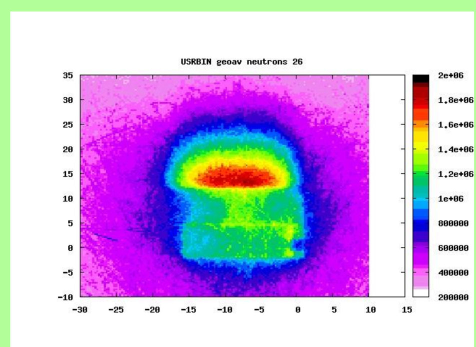
Nex DC280 cyclotron of the SHE factory at JINR

Next emittance measurement campain will be performed on new cyclotron DC280-SHE facility at JINR in Dubna. Due to radiological environment measurement of radiation field around high-energy accelerator is necessary. Some preliminary MC simulations have been performed to estimate neutron energy spectrum, dosimetry and induced activation of irradiated emittance-meter components.





Prompt activity after one week (Bq/cm³)



Equivalent dose rate after one week (pSv/s)

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