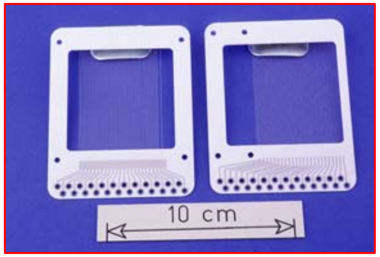
Transverse Profile Monitoring

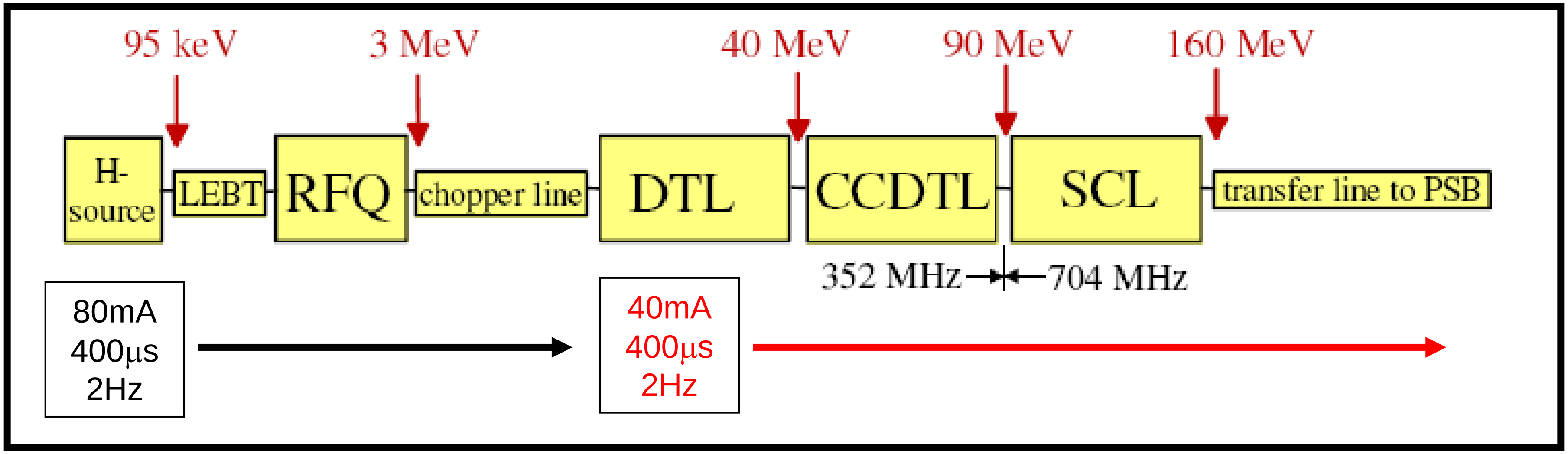


- Requirements
- SEM Grids / Wire Scanners
- Luminescent Screens
- Laser Wire Scanners

Main source of information

http://www.sns.gov/diagnostics/diag_docs.html

Transverse Profile Monitors : Requirements (1)



	LEBT	Chopper line	DTL	CCDTL	SCL	HEBT	Booster Injection	MB
Profile monitor	2	3	1	2	2	6	8	1

SEM Grids in preparation

Recuperate 3 Wire Scanners from LPI

25 Profile monitors

‘SEM Grids’
‘Wire Scanners’
‘Screens’
‘Laser Wire Scanners’

Transverse Profile Monitors : Requirements (2)

	LEBT	Chopper line	DTL	CCDTL	SCL	HEBT	Booster Injection	MB
Typical RMS Beam size (mm)	<60	<30	<2	<3	<3	<3	<3	<3
Spatial Resolution (mm)	**2**	**0.1**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
Time Resolution (μs)	20	*Tbc*	*Tbc*	*Tbc*	*Tbc*	*Tbc*	*Tbc*	*Tbc*
Dynamic Range	*Tbd*	*Tbd*	*Tbd*	*Tbd*	*Tbd*	*Tbd*	*Tbd*	*Tbd*
Space constraints	ok	**high**	**high**	**high**	**high**	Tbd	Tbd	ok

(Tbd = To be defined ; Tbc : To be confirmed)

- Spatial and temporal resolution should be easily achievable

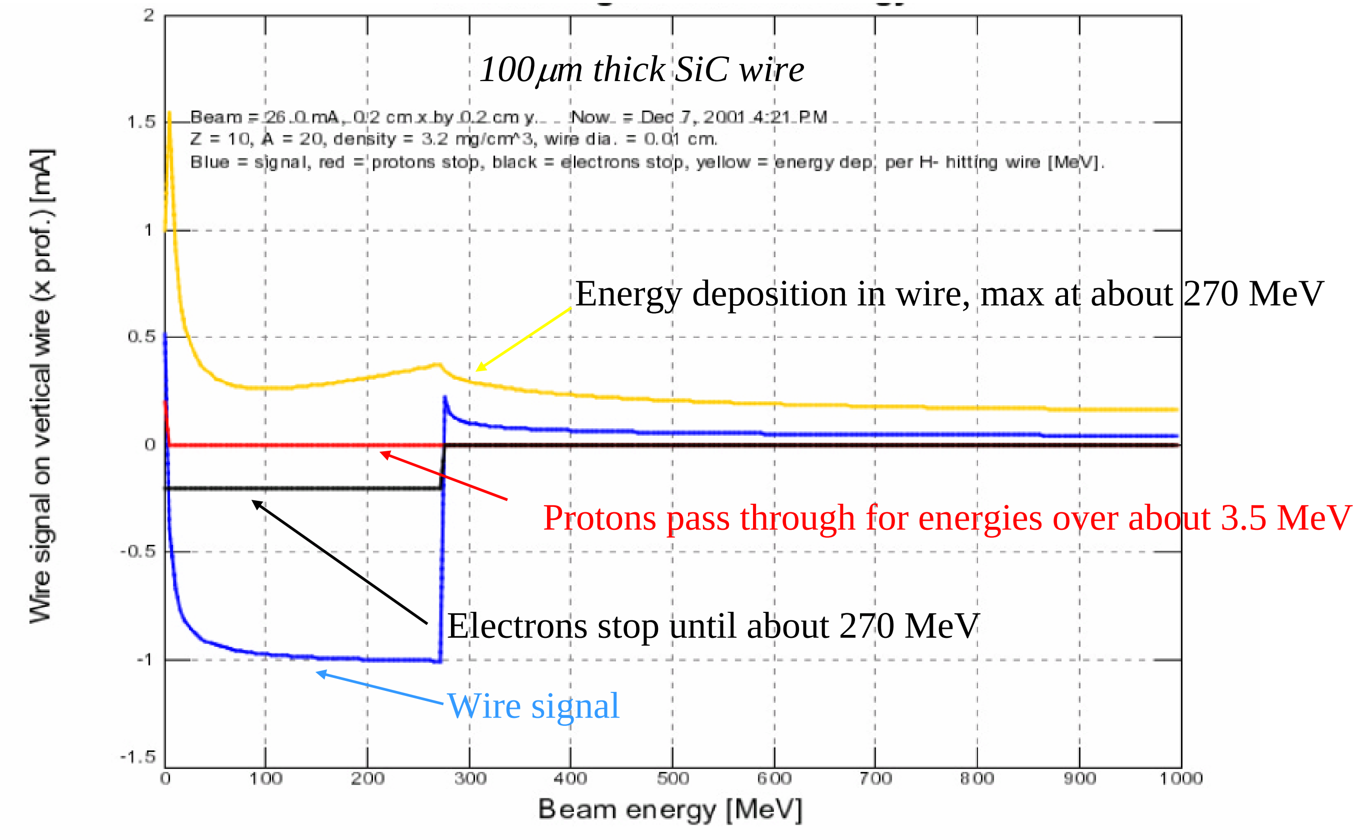
- Intense Beam (~10^{14} particles per pulse)
    - No problem for signal amplitude
    - Beam power and power density are high : Risk of Damage!

- Mechanical design is strongly constraint by space limitation

SEM Grid / Wire Scanners (1)

Expected signal

- SEM from H^-
- Electrons, protons stopping inside the material
- SEM from Electrons and Protons leaving the wire



Energy deposition in wire, max at about 270 MeV

Protons pass through for energies over about 3.5 MeV

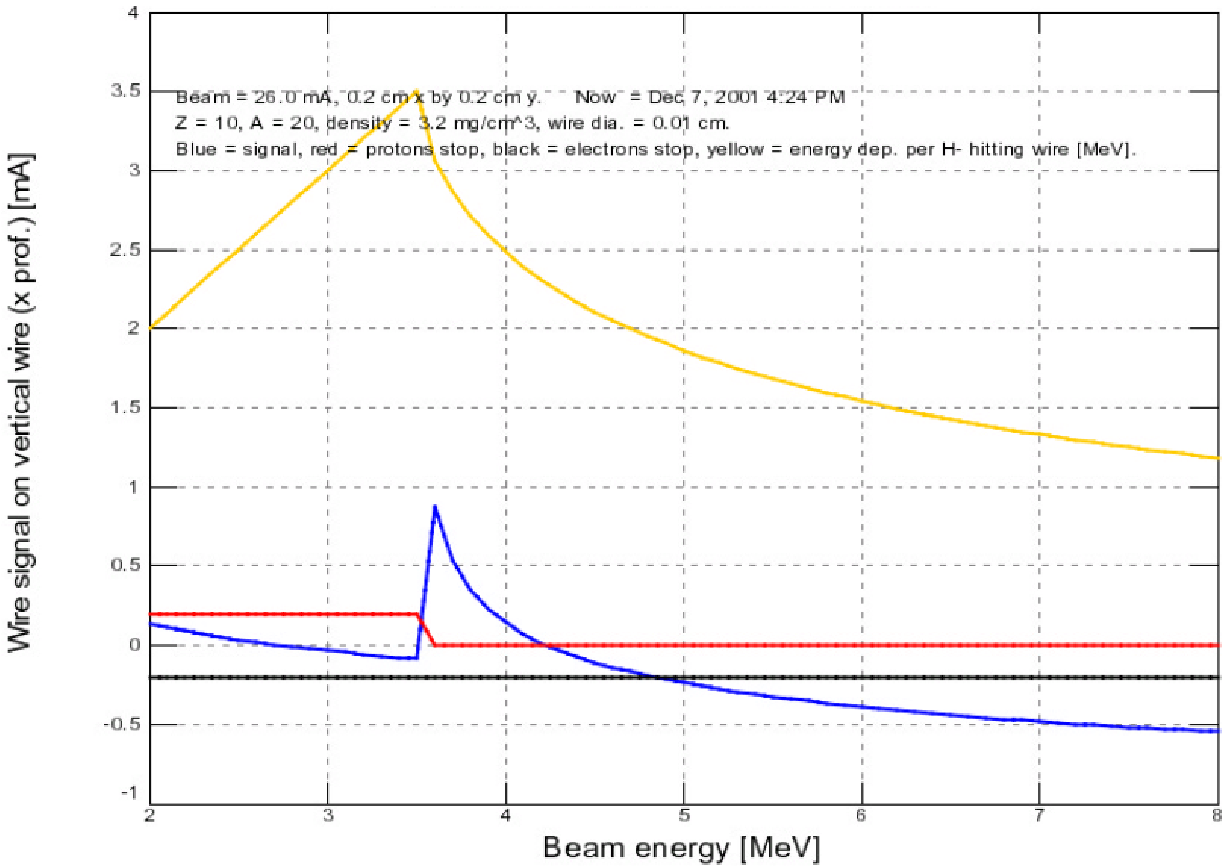
Electrons stop until about 270 MeV

Wire signal

Depends on wire material and its thickness

Calculations from M. Plum @SNS

SEM Grid / Wire Scanners (2)



Choice of the wire must be done precisely

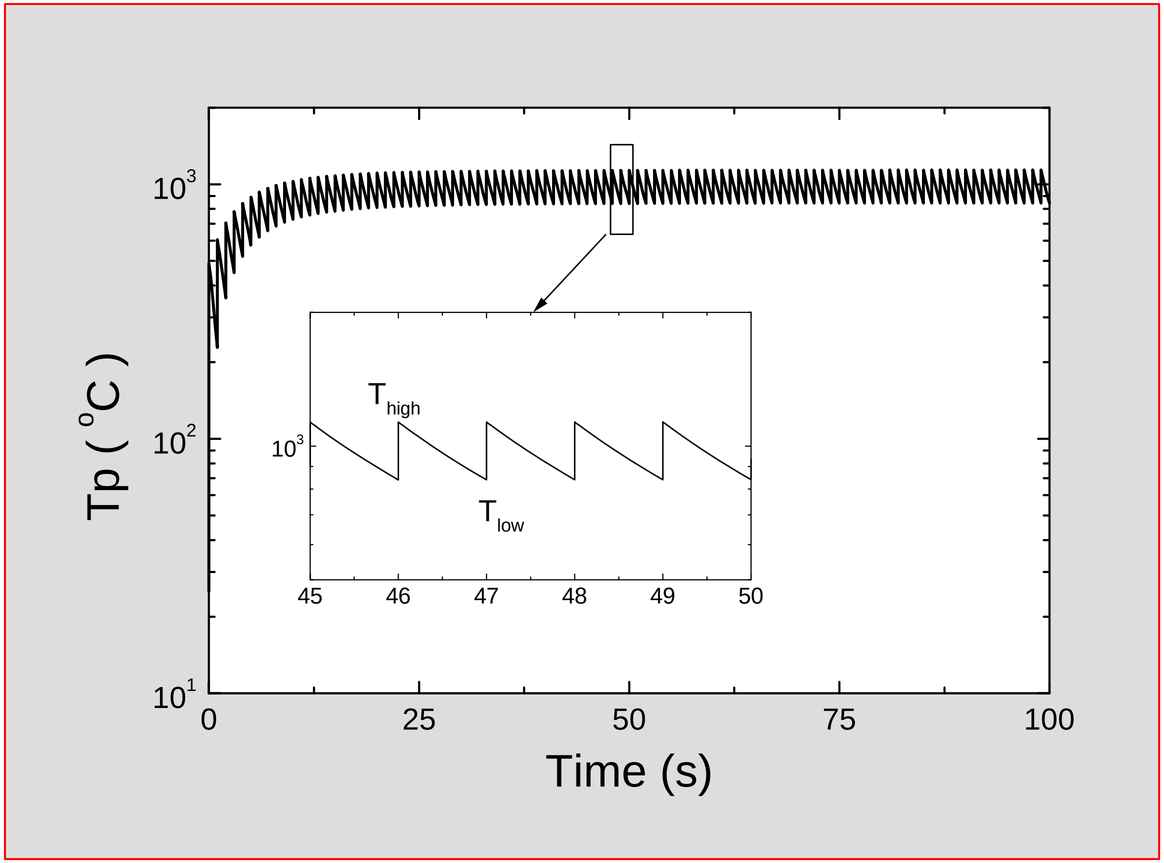
SEM Grid / Wire Scanners (3)

Thermal limitations

Cooling from Thermal conduction and black body emission

$$\boxed{\frac{\Delta T(r,t)}{\Delta t} = \frac{1}{c_p \rho}\left[\frac{dE}{dx}\rho e^{-\frac{r^2}{2\sigma^2}} N(t) - k\vec{\nabla}\cdot\vec{\nabla}T - \frac{2\varepsilon\sigma_s}{\delta}\left(T(r,t)^4 - T_0^4\right)\right]}$$

Heating from the beam



Electron beam characteristics :

- σ : RMS beam size
- Particle Flux : N(*t*)

Pulse duration, repetition rate

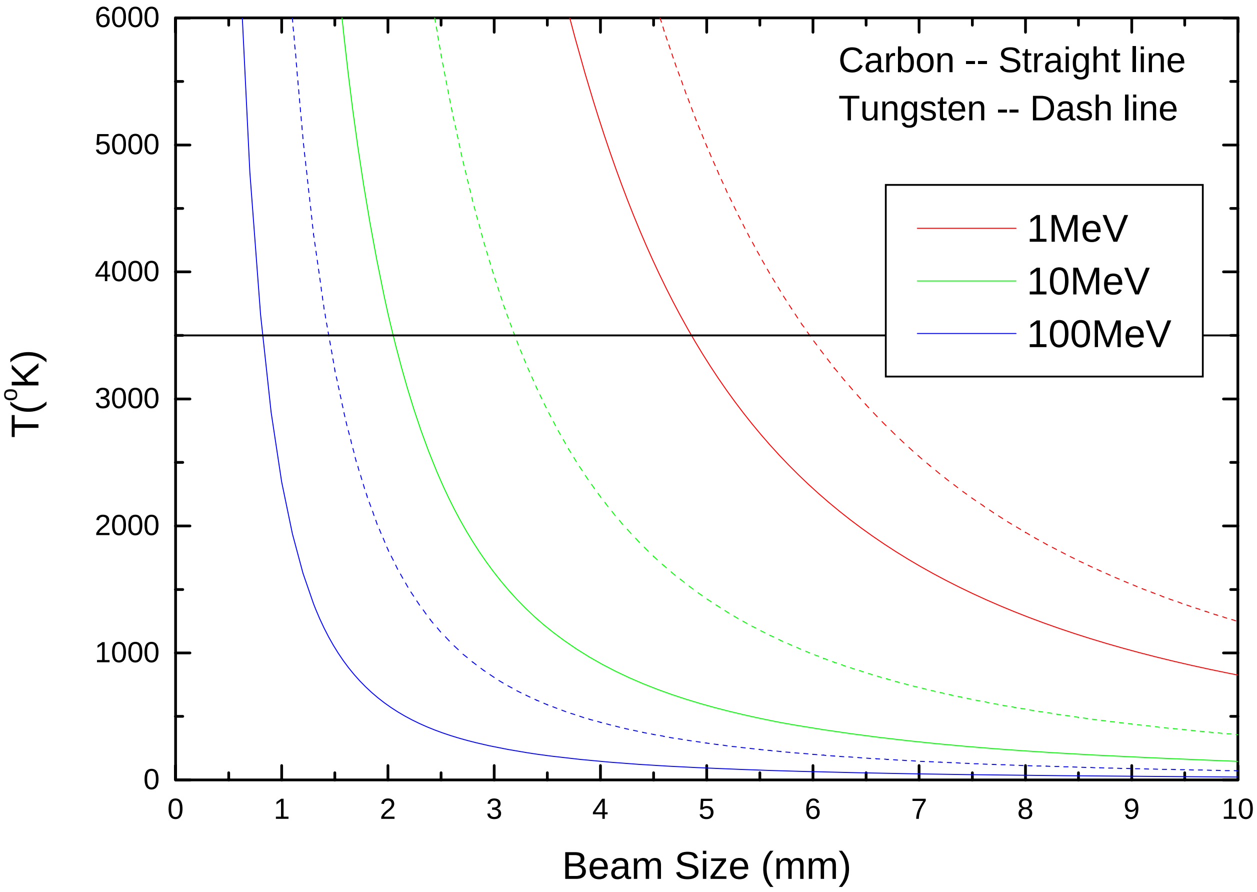
Target characteristics :

ε : Emissivity
δ : Thickness
c_p : Specific heat
ρ : Density
k : Thermal conductivity

σ_s the Stefan-Boltzmann constant

SEM Grid / Wire Scanners (4)

ΔT for different materials and different beam energies

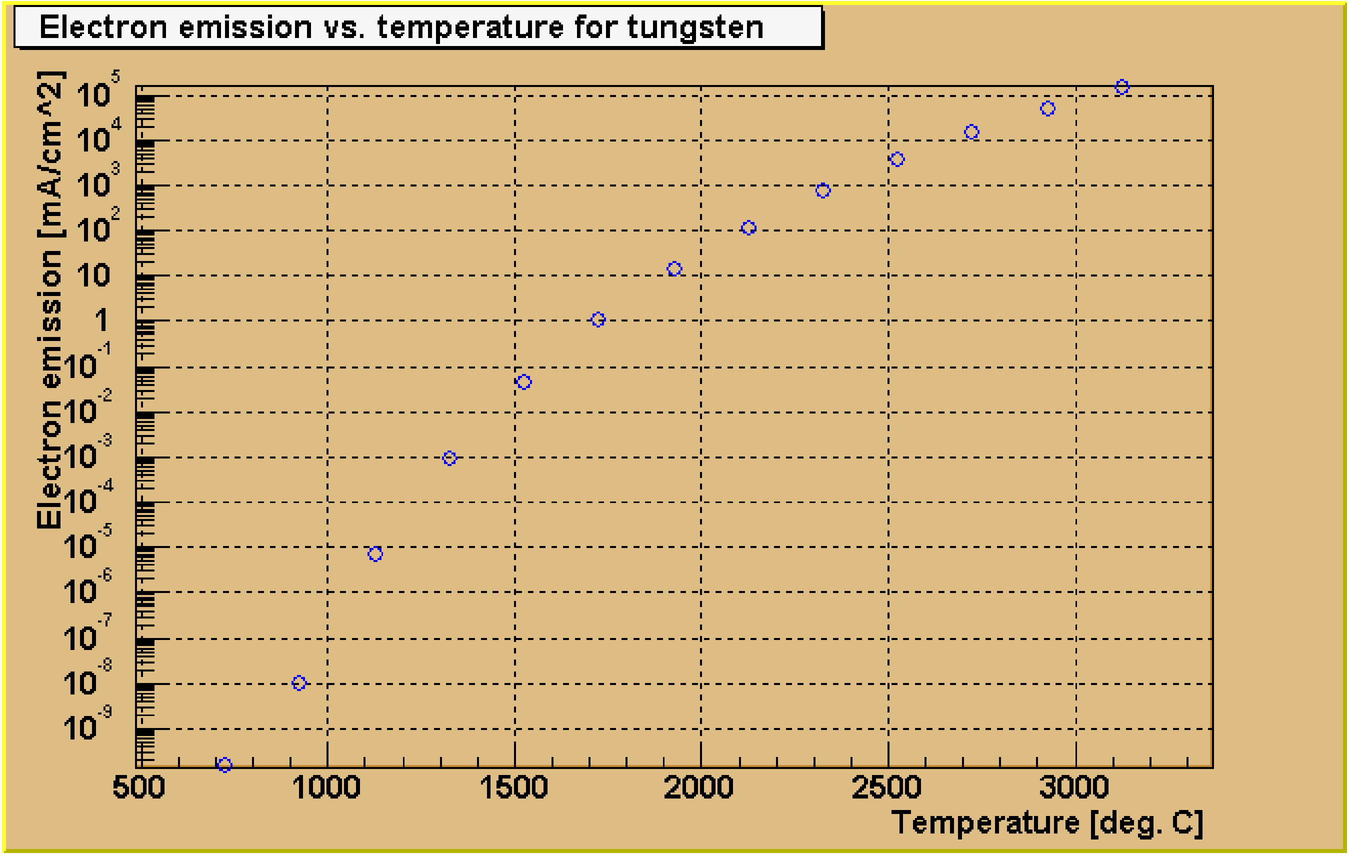


There are strong limitations to observe the full beam @low energies

Reduce the pulse length

SEM Grid / Wire Scanners (5)

- The peak thermo-ionic current should be at least 100 times lower than the peak secondary electron emission current to avoid substantial contribution to the secondary electron signal.
- Thermo-ionic emission proportional to the wire surface (diameter)

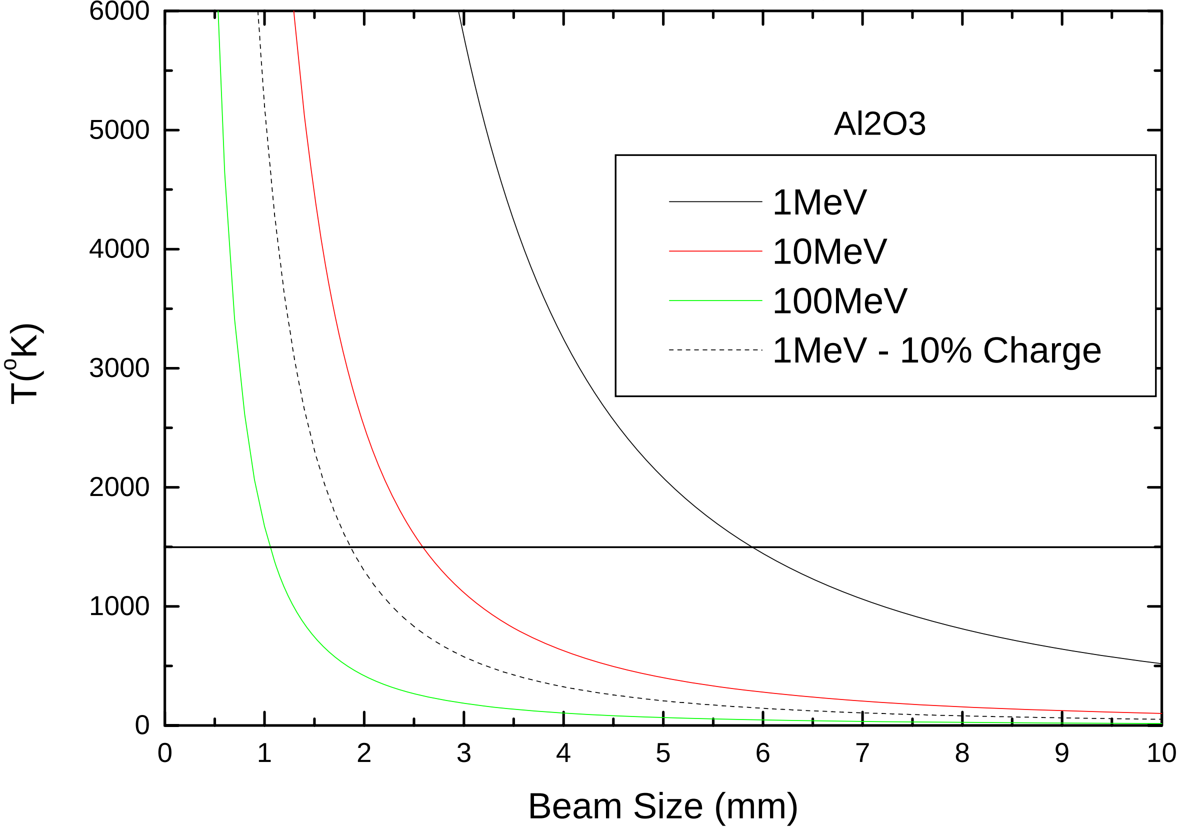


Parameter to be considered in the optimization

Luminescent screens

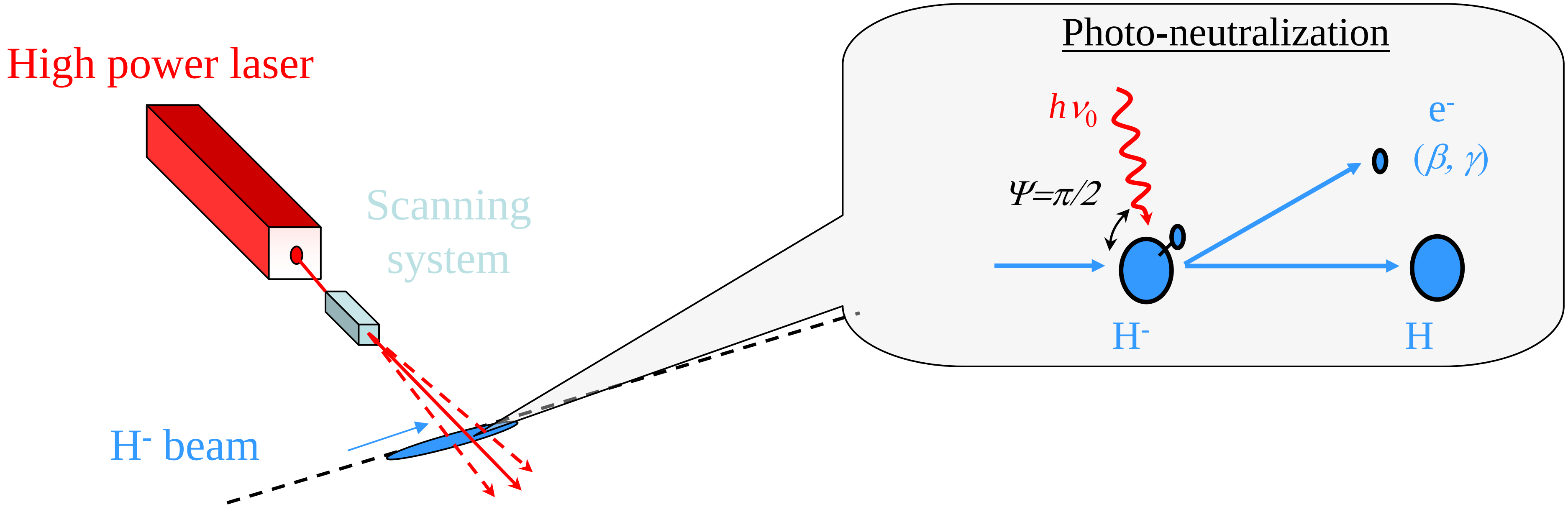
- No limitation from light intensity
- 0.5mm Spatial resolution is easy
- Provide more information than just profiles
- No time resolution with thermal resistant Al_2O_3
- Space constraint to be checked
- Thermal limitation

Thermal limitations for $Al_2O_3:Cr^{3+}$ screen

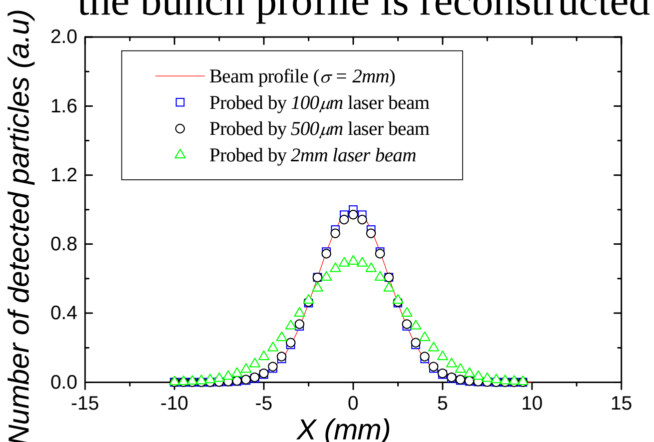


Can be used at higher energies with reduced beam charge

Laser Wire Scanner (1)



‘By counting the number of the photoneutralization as a function of the laser position the bunch profile is reconstructed ‘



Based on

- The detection of released electrons using a magnet and a collector
- Measured the decrease of H$^-$ with a wall current monitor

Laser Wire Scanner (2)

Laser Beam

λ_0 : Laser wavelength

τ_{laser} : Laser pulse duration

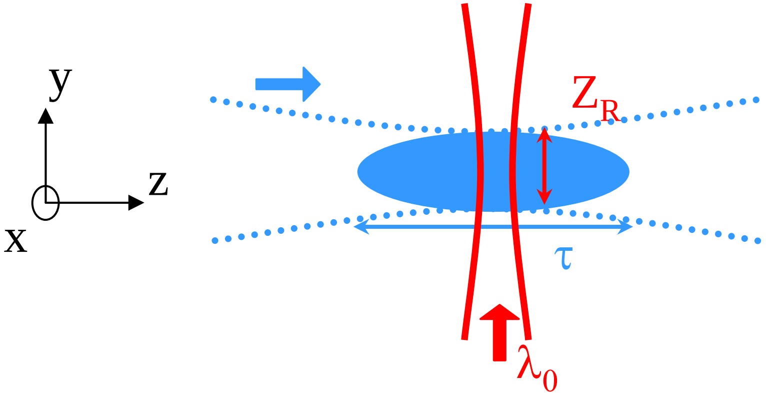
σ_ω : RMS spot size

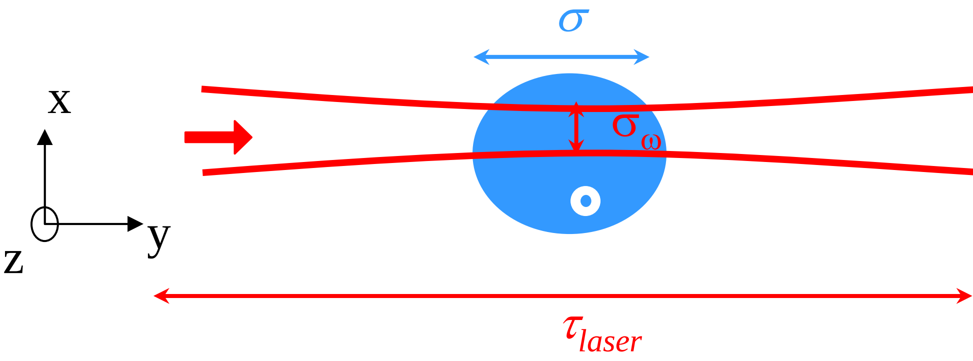
Z_R : Rayleigh range

Particle Beam

τ : RMS Bunch length

σ : Transverse RMS beam size





- The number of interactions is given by $N \approx \dfrac{\sigma \cdot N_p \cdot N_{laser} \cdot \tau_{laser}}{A \cdot \tau}$

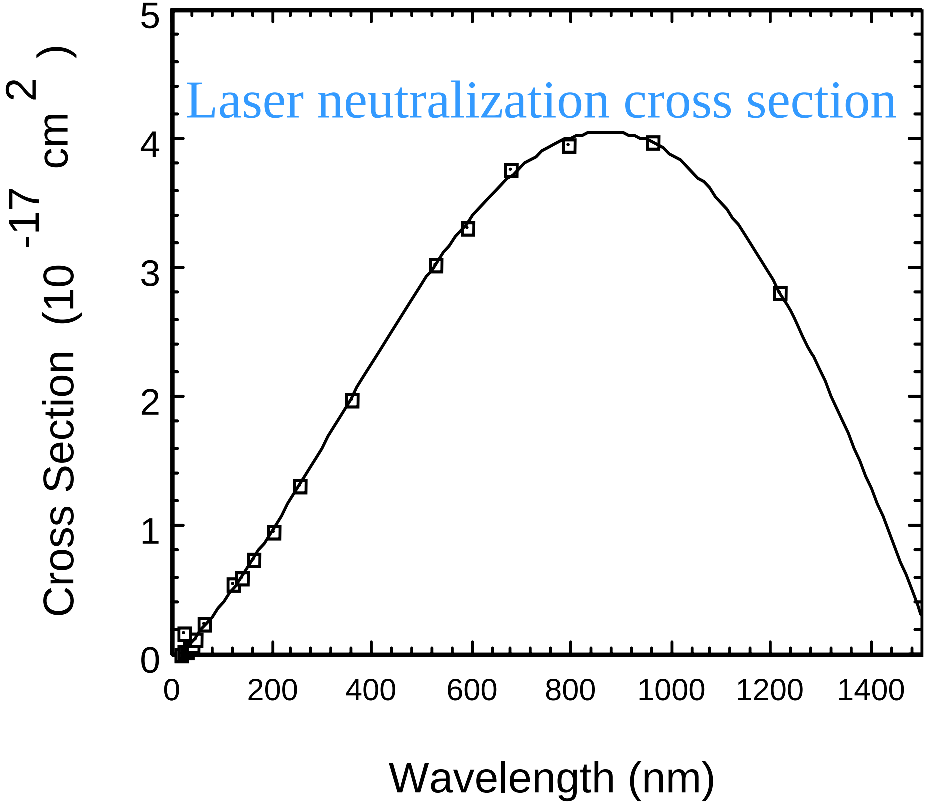
with A the interaction area, N_p and N_{laser} are the number of particles and photons in A

- Efficient for small beam size
- Need high power laser

Laser Wire Scanner (3)

- First ionization potential for H^- ions is 0.75eV. Photons with $\lambda<1500$nm can remove an electron leaving neutral H plus electron

- Photo-neutralization cross section is equal to $\sigma \sim 4\ 10^{-21}\ m^2$



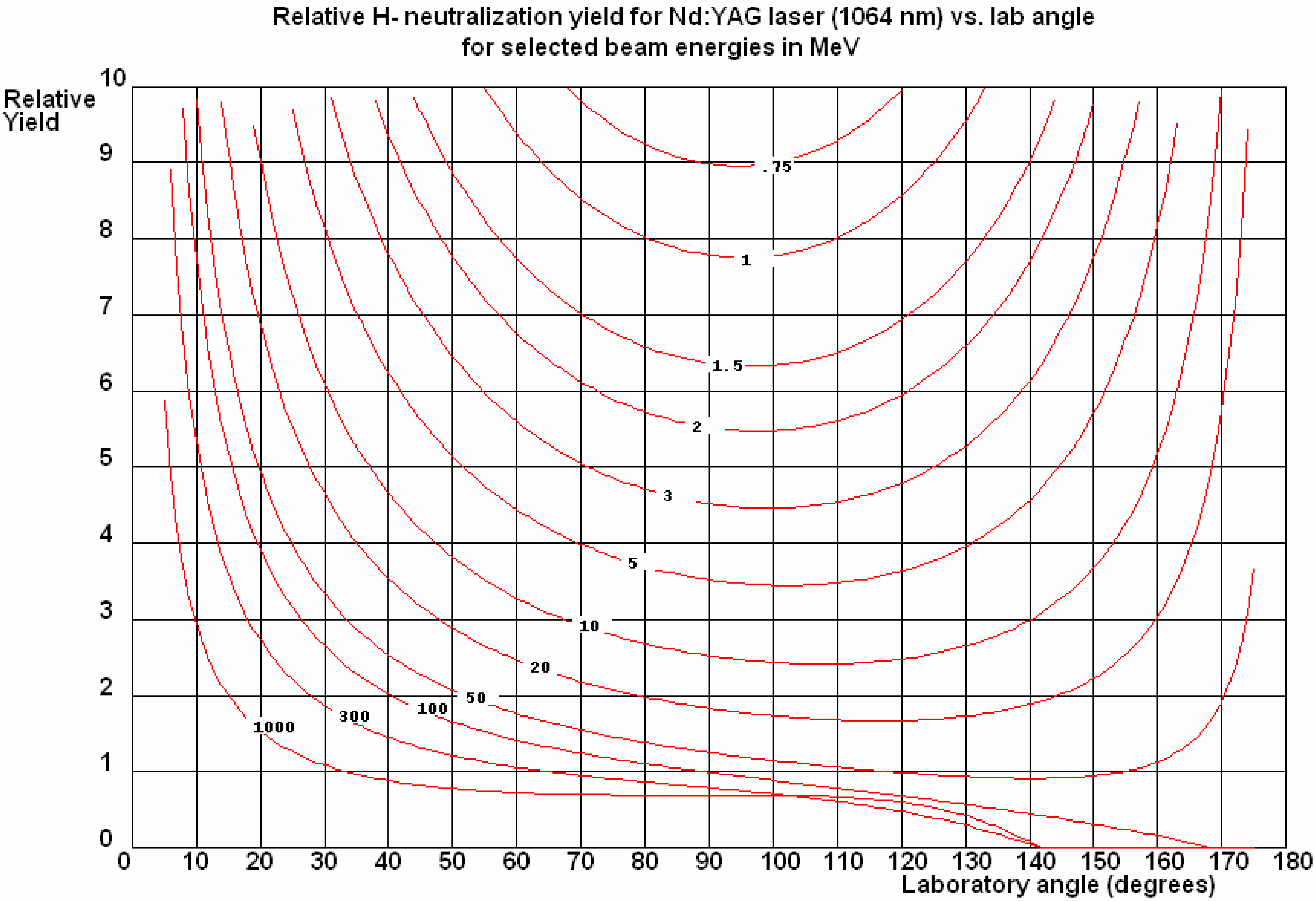
Nd:YAG laser has $\lambda=1064$ where the cross section is about 90% of the maximum.

*J.T. Broad and W.P. Reinhardt, Phys. Rev. A14 (6) (1976) 2159.

Laser Wire Scanner (4)

Evolution with
Beam energy

$$\lambda \approx \frac{\lambda_0}{\gamma(1-\beta\cos(\psi))}$$



Laser Wire Scanner Versus Wire scanner

Laser Wire

- Non perturbative method
- Time resolution possible
- Limited to “small beam size” (~ 2mm) ?
- Limited dynamic range : Possible of background (Stripping from residual gas, Beam losses)
- External magnets are required
- Higher Cost ?

Conventional Wire

- High risk of damage
- Signal to noise not a problem
- Maintenance requires vacuum access
- Very radiation hard

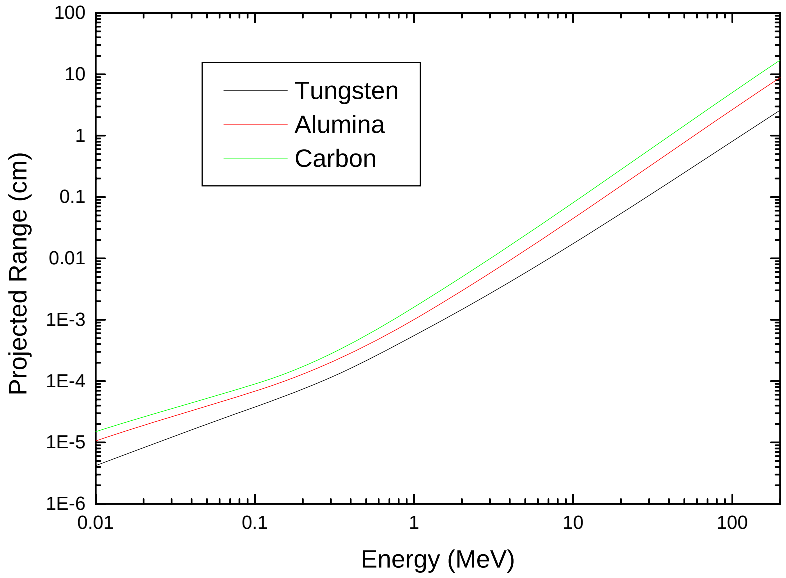
Conclusions

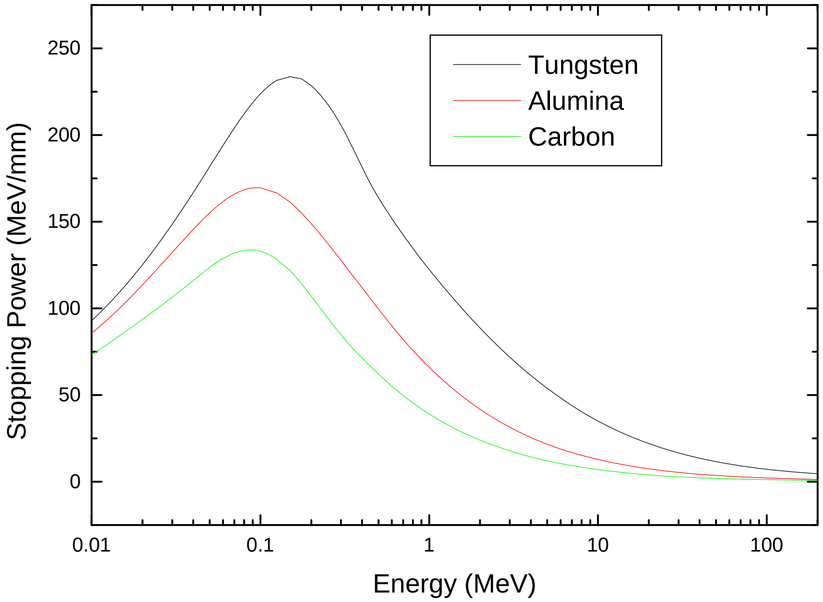
- Dynamic range and time resolution to be defined for each monitor *(design of the electronic)*

- Choice of detector is strongly constrained by:
  - Limited space available
  - Important thermal limitations for any intercepting devices (SEM/Wire/Screen)
  - Choice of the Wire to be studied

- Screens and Laser wire scanner present some advantages and should be investigated

Stopping power and range



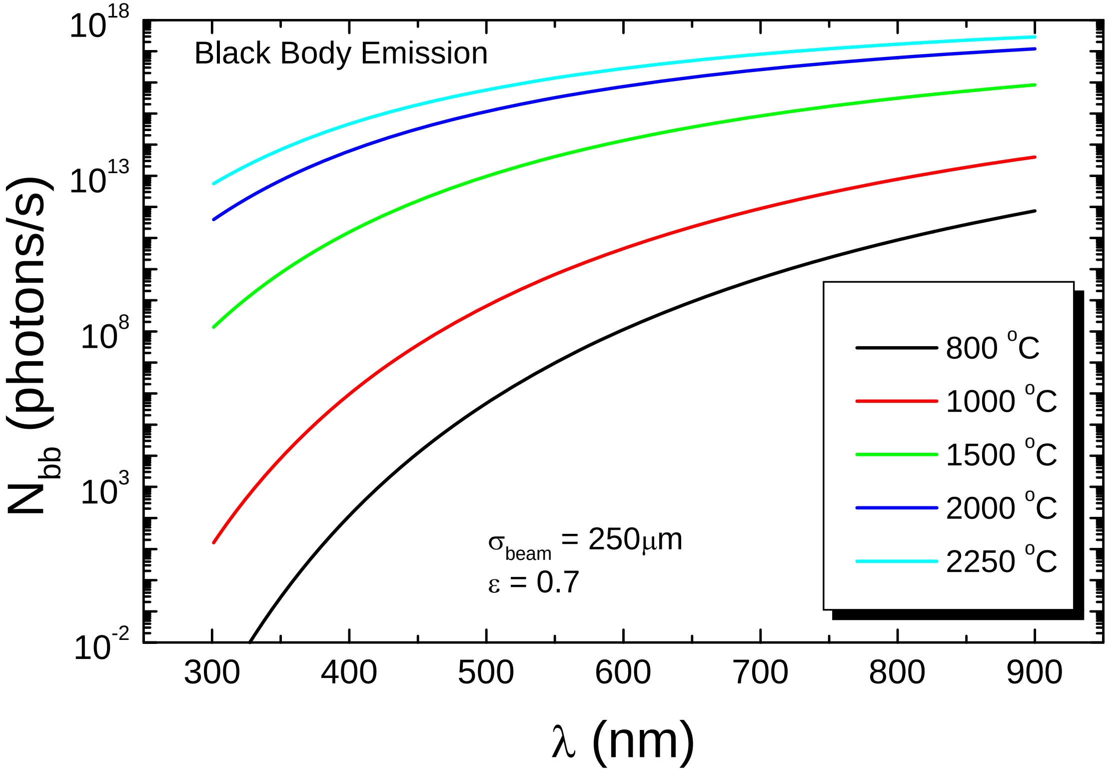


Luminescent screens

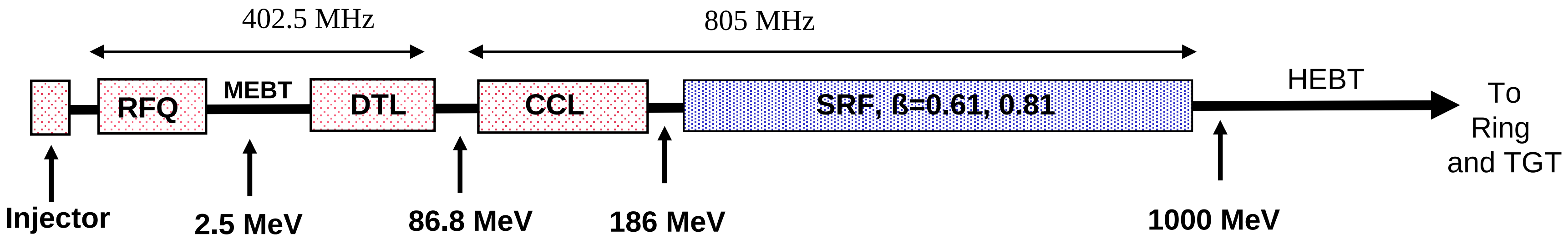
The number of Black body photons emitted per second in the wavelength range [λ_a, λ_b] and in 2π sr is given by:

$$N_{BB} = \int_{\lambda_a}^{\lambda_b} \frac{2\pi c}{\lambda^4} \frac{2\pi\sigma^2\varepsilon}{e^{\frac{hc}{kT\lambda}} - 1} d\lambda$$

k the Boltzmann constant, h the Planck constant, and c the speed of light.



LANL diagnostics deliverables



MEBT
5 WS (elec. only)
6 BPM (elec. only)
2 Sl&Col (act. only)

DTL
5 WS
10 BPM
6 CM (p/u only)
5 ED/FC

D-plate (7.5 MeV)
1 WS
3 BPM
1 CM (p/u only)
1 ED/FC
2 Sl&Coll emit
1 Phosphor screen
1 8 seg. halo scraper
1 Beam stop / F-Cup

CCL
8 WS
12 BPM
2 CM (p/u only)
1 ED/FC

SCL
32 WS (16 elec.)
32 BPM

HEBT
3 WS (dumps)
22 BPM (elec. only)

RTBT
1 Harp

Key
WS = wire scanner
BPM = beam position monitor
Sl&Col = slit and collector emittance station
CM = current monitor
ED/FC = energy degrader & Faraday Cup

SNS Thermo-ionic emission vs temperature

Parameter	**x profile**	**y profile**
Wire type	Tungsten	Tungsten
Length of thermal emission	14 cm	6.5 cm
Results – 25 micron dia. tungsten		
Wire area	0.11 cm^2	0.051 cm^2
Max allowable thermal emission**	0.0056 mA	0.021 mA
Max allowable thermal emission	0.051 mA/cm^2	0.41 mA/cm^2
Max allowable temperature	1500 deg. C	1600 deg. C
Results – 100 micron dia. tungsten		
Wire area	0.44 cm^2	0.20 cm^2
Max allowable thermal emission**	0.026 mA	0.098 mA
Max allowable thermal emission	0.059 mA/cm^2	0.49 mA/cm^2
Max allowable temperature	1500 deg. C	1600 deg. C

** 1% of peak wire signals in Table 1.

SNS Wire scanner signal levels

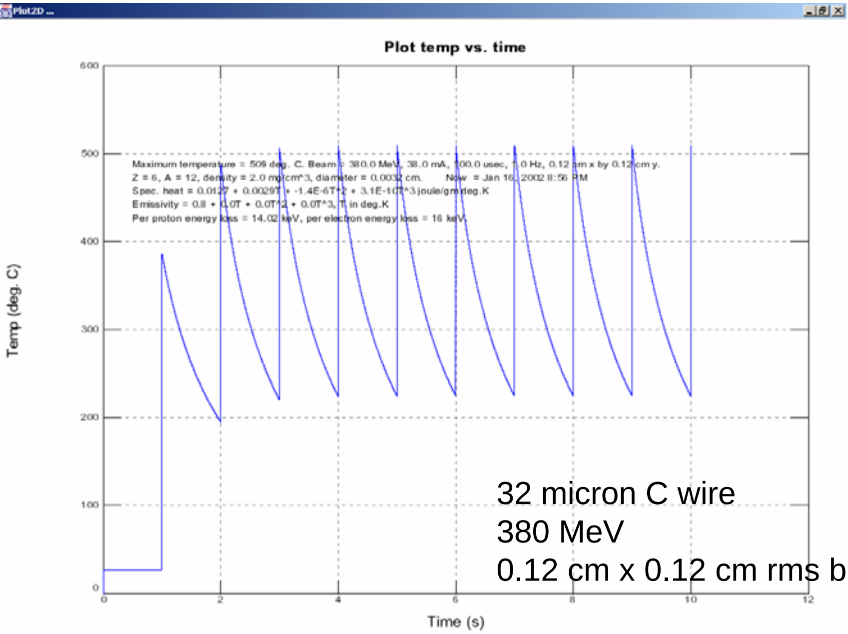
- 32 micron dia. carbon wire.
- Electronics should measure down to 1% of weakest signal from 5 mA avg. beam current, and up to about 200% of strongest signal from 26 mA avg. beam current
- Total current range is 16 nA to 1.8 mA.

Signals at center of beam, 26 mA avg. beam current

Location	Energy (MeV)	rms, min (cm)	signal (uA)	rms, max (cm)	signal (uA)
MEBT	2.5	0.1	–81	0.37	–22
DTL 1	7.5	0.092	–480	0.17	–260
DTL 2	22.9	0.086	–670	0.15	–380
DTL 3	39.8	0.10	–610	0.11	–550
DTL 4	56.5	0.073	–850	0.13	–480
DTL 5	72.5	0.11	–570	0.11	–570
DTL 6	86.8	0.071	–890	0.14	–450
CCL 1	88 – 105*	0.10	–640	0.19	–330
CCL 1	108* - 140	0.11	190	0.19	28
CCL 2	140 – 186	0.12	45	0.22	18
SCL 1	186 – 380	0.16	25	0.22	11
SCL 2	380 – 1000	0.12	21	0.22	8.0
D-plate	7.5	0.09	–495	0.23	–195

*Transition from neg. to pos. signal at about 107 MeV.

Note: Signal levels are accurate to about a factor of two.



Maximum temperature = 509 deg. C. Beam = 380.0 MeV, 38.0 mA, 100.0 usec, 1.0 Hz, 0.12 cm x by 0.12 cm y.
Z = 6, A = 12, density = 2.0 mg/cm^3, diameter = 0.0032 cm.   Now = Jan 16, 2002 8:56 PM
Spec. heat = 0.0127 + 0.0029T + -1.4E-6T^2 + 3.1E-10T^3 joule/gm deg.K
Emissivity = 0.8 + 0.0T + 0.0T^2 + 0.0T^3, T in deg.K
Per proton energy loss = 14.02 keV, per electron energy loss = 16 keV.

32 micron C wire
380 MeV
0.12 cm x 0.12 cm rms beam

SNS Wire Temperature

- 32 micron C wire.
- Temperatures at center of beam.
- Max temp is 1225 deg. C.
- Requirements are met for all except MEBT (outside the scope of this review).

Location	Energy (MeV)	x (rms, cm)	y (rms, cm)	Temp (^{o}C)	Temp (^{o}C)
MEBT[0]	2.5	0.1	0.37	1370[1]	
DTL 1	7.5	0.092	0.17	730[1]	1180[2]
DTL 2	22.9	0.086	0.15	530[1]	950[2]
DTL 3	39.8	0.10	0.11	530[1]	940[2]
DTL 4	56.5	0.073	0.13	580[1]	1010[2]
DTL 5	72.5	0.11	0.11	530[1]	940[2]
DTL 6	86.8	0.14	0.071	620[1]	1055[2]
CCL[3]	88 – 186	0.11	0.11	592[1]	1019[2]
SCL[4]	186 – 1000	0.16	0.16	320[5]	665[6]
D-plate	7.5	0.23	0.09	620[1]	1055
D-plate	7.5	0.21	0.21	400[1]	780[2]

[0] WS #5
[1] 1 Hz, 50 us, 26 mA beam
[2] 10 Hz,
[3] 106 MeV
[4] 200 MeV
[5] 1 Hz, 100 us, 26 mA
[6] 10 Hz, 100 us, 26 mA

SNS Laser Wire Scanner

Single laser station

1) More resources available for a higher quality laser
2) Requires some sort of distribution system

One laser per station

1) Simple
2) Quality of laser severely limited by the budget

Choice: Single laser

SNS Laser Wire Scanner

Q-switched laser

1) Less expensive

2) Not necessary to match the phase of the ion pulse train

3) Only 1% of the laser energy overlaps with the ion pulses

Mode-locked laser

1) All of the optical energy available for neutralization

2) Because less energy per pulse is needed, optical damage is less likely

3) Longitudinal profiling also possible

4) More expensive

5) Pulses must be properly timed

Choice: Q-switched laser

SNS Laser Wire Scanner

Distribution by fiber

1) Optical damage likely, especially with longer, Q-switched pulses.
2) Radiation darkening would be a serious problem.
3) For mode-locked pulses, additional dispersion compensation would be required

Distribution by direct beam propagation

1) Optical damage less likely
2) System should accommodate multiple laser systems
3) Active stabilization may be necessary

Choice: Direct beam propagation

SNS Laser Wire Scanner

Beamline optics in vacuum

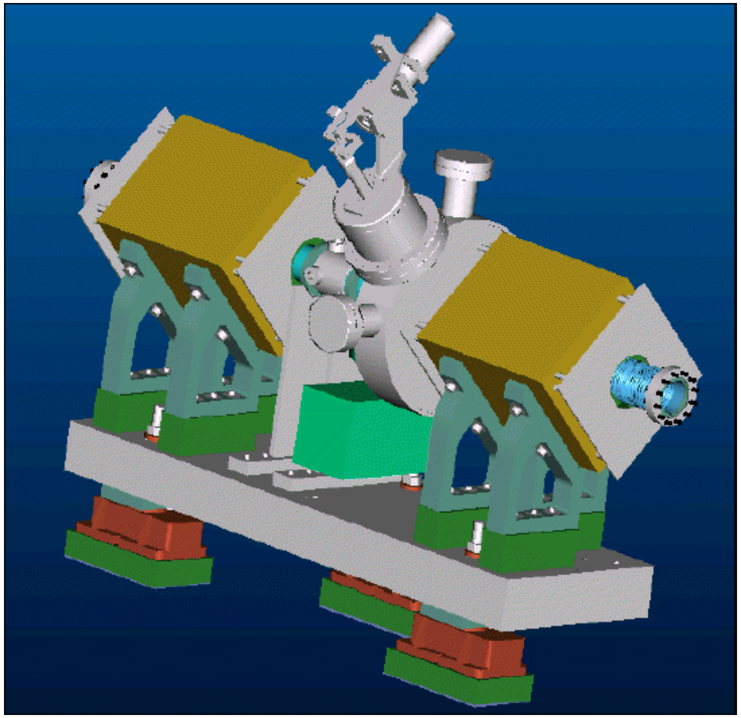
1) Requires "vacuum-safe" optical stages and mirror mounts

Choice: Dry purge

Beamline optics in dry purge

1) Special stages and mounts not required

2) Purge should be sufficient to keep optics clean.



SNS Laser Wire Scanner

- Sources of background are
  - Stripping on residual gas
    - 38mA; 200MeV; 1e-9 torr nitrogen; 1ms: 3.3e6 electrons/m
      - 10^{-3} background in 10cm detector
    - 20mA; 200MeV; 1e-9 torr nitrogen; 50us: 8.7e4 electrons/m
      - $< 10^{-4}$ background in 10cm detector
  - Beam losses
    - 1W/m -> Ne = 2e6 for 10cm^2 collector area at 200MeV
      Ne = 4e5 for 10cm^2 collector area at 1000MeV
    - Can be major source of background (~1e-2)
      - Time gating can help
      - Experience from other machines? (PSR, etc.)