New Methods for Diagnostics of High Intensity Electron Beams

Beam Instrumentation Workshop 2012

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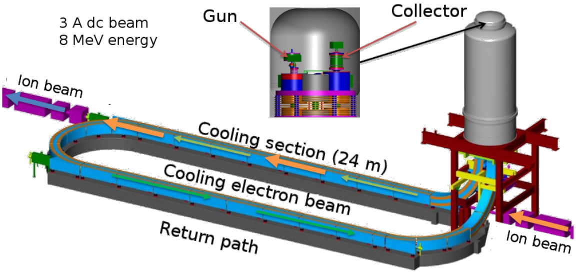
Outline

High Energy Cooling

New cooling devices

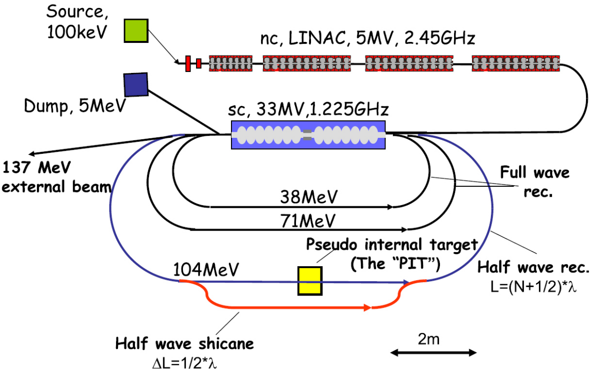
- Cooling of high energy ion beams (15 GeV at HESR)
- High energy cooling beam (2 MeV at COSY, 8 MeV at HESR and ENC)
- Cooling beam guided in strong magnetic field ($\approx$ 0.5 T)



Energy Recovery Linacs

MESA (**M**ainzer **E**nergy recovering **S**uperconducting **A**ccelerator)

- High intensity beam: 50 kW injector; $> 1\,\mathrm{MW}$ accelerator
- No synchrotron radiation in injector and merger

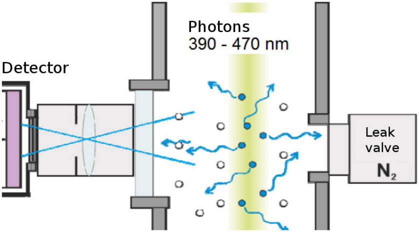


Beam Induced Fluorescence

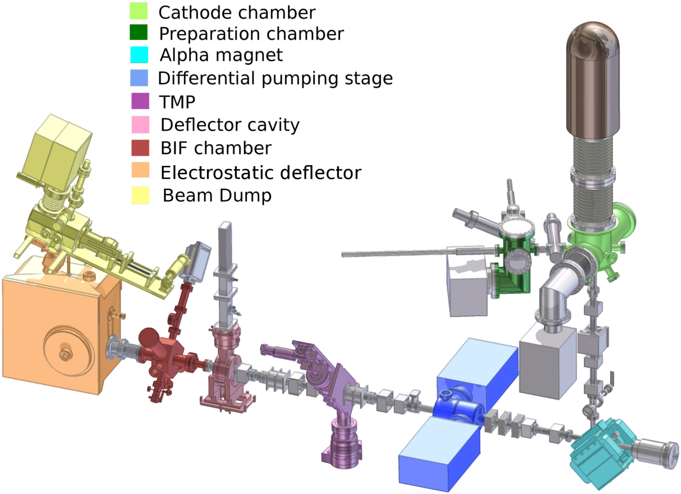
Electron beam induced signals

- Beam excites residual gas atoms/molecules
- Residual gas emits photons
- Imaging photons on detector
- Expected event rates: $2 \times 10^4\,\mathrm{cm}^{-1}\mathrm{s}^{-1}$ @ $10^{-5}\,\mathrm{mbar}$ $\Rightarrow$ Highly sensitive detector required (PMT)

Schematic setup



Test Setup at PKAT

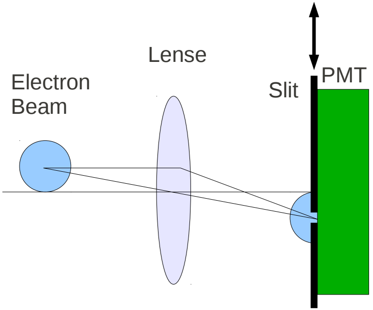


Conditions for BIF Measurements

Beam energy	$100\,\mathrm{keV}$
Beam current	$100\,\mu\mathrm{A}$
Residual gas pressure	$\approx 10^{-5}\,\mathrm{mbar}$
PMT voltage	$1000\,\mathrm{V}$
Slit width	$0.2\,\mathrm{mm}$

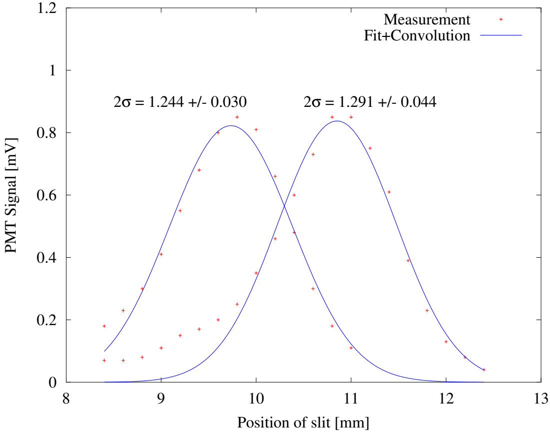
Different detection modes:

- Analog: Amplifier $10^5\,\mathrm{V/A}$
- Counting mode: Integration time $30\,\mathrm{s}$



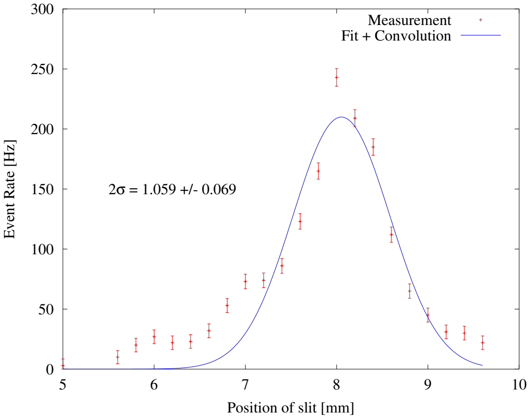
Preliminary Results I

Detection mode: analog



Preliminary Results II

Detection mode: counting (500 μA peak current; duty cycle 0.1)
Statistical errorbars only



Beam Spot on YAG Screen

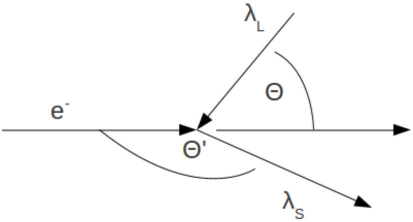
- YAG screen behind BIF chamber (distance 30 cm)
- 500 $\mu\mathrm{A}$ peak current; duty cycle 0.01
- Beam spot not round
- Beam has halo
- Explains asymmetric shape of beam profile

Summary

- BIF also works for electron beams
- Beam profile measurements possible
- Detector with spatial resolution (ICCD)
  $\Rightarrow$ Beam profile measurement in $\approx 10\,\mathrm{s}$
- Analysis ongoing
- Cooler: $1\,\mathrm{A}$; $10^{-9}\,\mathrm{mbar}$
- ERL: $10 - 100\,\mathrm{mA}$; $10^{-7} - 10^{-8}\,\mathrm{mbar}$
  $\Rightarrow$ same event rates

Principle of Thomson Scattering

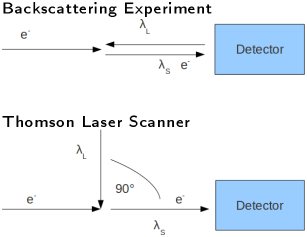
- laser field excites electron oscillations
- Electrons scatter photons
- Relativistic Doppler shift leads to higher photon energy



C. Habfast et al.: Measurement of laser Light Thomson-Scattered from a Cooling Electron Beam, Appl. Phys. B 44, 87-92 (1987).

Doppler Shift

- Doppler shift is given by
  $\lambda_S = \lambda_L \frac{(1+\beta cos(\Theta'))}{(1+\beta cos(\Theta))}$
- For head-on/backscattering:
  $\Theta = 0°, \Theta' = 180°$
  $\lambda_S = \lambda_L \frac{(1-\beta)}{(1+\beta)}$
- For 90° Thomson Laser Scanner:
  $\Theta = 90°, \Theta' = 180°$
  $\lambda_S = \lambda_L(1-\beta)$



C. Habfast et al.: Measurement of laser Light Thomson-Scattered from a Cooling Electron Beam, Appl. Phys. B 44, 87-92 (1987).

Event Rates

- Determined by Thomson cross section
  $\frac{d\sigma}{d\Omega} = \frac{1}{2} r_e^2 (1 + cos^2(\Theta'))$ $\quad r_e = 2.818 \cdot 10^{-15}\,\mathrm{m}$
- Event rate is given by
  $R = \frac{1}{2} r_e^2 (1 + cos^2(\Theta') N_L P n_e \epsilon \Delta\Omega l \frac{1+\beta cos(\Theta)}{(1+\beta cos(\Theta'))\gamma}$
  with
  N_L = Number of incident photons per Joule
  P = Laser power
  n_e = Electron density
  ϵ = Detector system efficiency
  $\Delta\Omega$ = Solid angle
  l = Interaction length
  $\frac{1+\beta cos(\Theta)}{(1+\beta cos(\Theta'))\gamma}$ = Lorentz transformation

J. Berger et all: Thomson Scattering of laser Light from a Relativistic Electron Beam, Physica Scripta.

Vol. T22, 296-299, 1988.

Event Rates for Different Setups

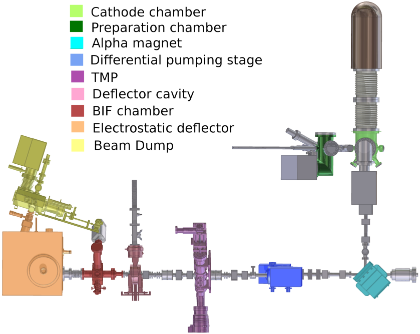
- TLS setup $\Theta = 90°, \Theta' = 180°$
- Beam current $1\,\mathrm{A}$ at $1\,\mathrm{cm}$ diameter
- Average laser power $100\,\mathrm{W}$
- Detector system efficiency $\epsilon = 0.2$, Solid angle $\Delta\Omega = 10\,\mathrm{msr}$

Beam energy	λ_L	λ_S	Event rate
$40\,\mathrm{keV}$ (Test setup)	$1.03\,\mu\mathrm{m}$	$712\,\mathrm{nm}$	$14\,\mathrm{s}^{-1}$
$2\,\mathrm{MeV}$ (COSY cooler)	$10.6\,\mu\mathrm{m}$	$220\,\mathrm{nm}$	$6.1 \cdot 10^2\,\mathrm{s}^{-1}$
$4.5\,\mathrm{MeV}$ (HESR cooler)	$10.6\,\mu\mathrm{m}$	$50\,\mathrm{nm}$	$1.2 \cdot 10^3\,\mathrm{s}^{-1}$
$8\,\mathrm{MeV}$ (ENC cooler)	$10.6\,\mu\mathrm{m}$	$20\,\mathrm{nm}$	$2.1 \cdot 10^3\,\mathrm{s}^{-1}$

Conditions for TLS @ PKAT

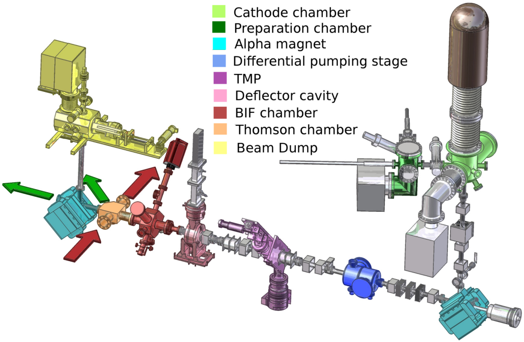
PKAT HV power supply $3\,\mathrm{mA}$ @ $100\,\mathrm{keV}$
$\Rightarrow$ Pulsed electron beam
$\Rightarrow$ Laser with same time structure for cathode
$\Rightarrow$ Synchronization Thomson laser $\leftrightarrow$ cathode laser

- Thomson laser power $> 100\,\mathrm{W}$
- Wavelength $1030\,\mathrm{nm}$



Beam Profile Measurement with TLS

- $100\,\mathrm{mA}$ peak current
- Duty cycle 2×10^{-3}
  $\Rightarrow$ average current $200\,\mu\mathrm{A}$
- $3\,\mathrm{mm}$ beam diameter
- $100\,\mathrm{W}$ average laser power
- $\Delta\Omega = 0.01$ $(\Theta' = 135°)$
- $\epsilon = 0.2$
- Event rate $13\,\mathrm{s}^{-1}$
- Background (BIF) $\approx 2\,\mathrm{s}^{-1}$
  and other sources e.g. x-rays

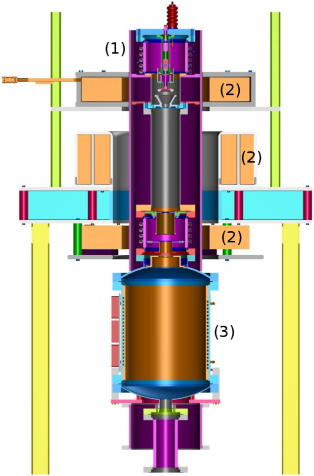


Summary & Outlook

TLS

- Thomson scattering
- Expected event rates
- Implementation into PKAT

Implementation of both diagnostic methods in HESR cooler test setup



(1) DC Gun
(2) Solenoids
(3) Collector

Current 3 A
Energy 40 keV
Diameter 1 cm

Thank you for your attention