Air Fluorescence in the Laboratory using Low Energy Electron Beam Exciatation

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I. Background

II. Technolgy of low energy electron beam excitation

III. Preliminary results from air:

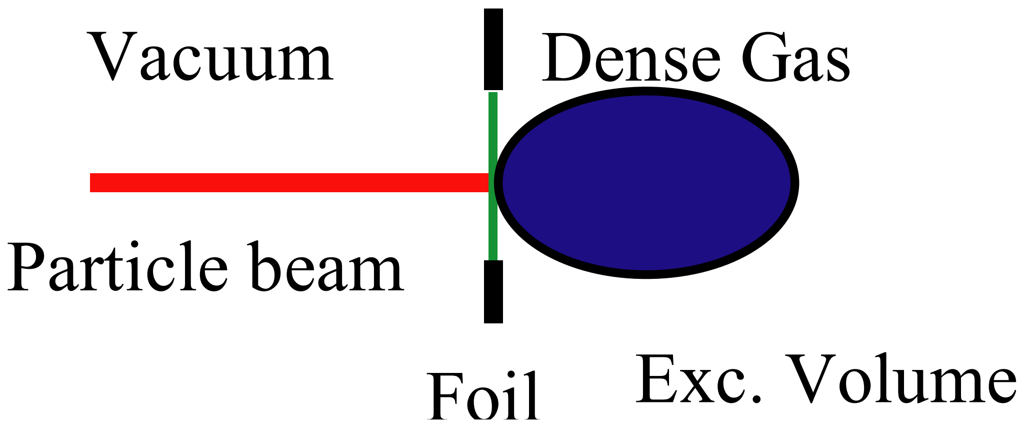
   a) Spectra
   b) Pressure effects
   c) Gas kinetics and humidity effects
   d) Energy conversion

I Background

Rome group: "Well known"
TU-Munich group: "Particle beam induced light emission"

- Heavy ion beam pumped lasers
  (Munich Tandem Lab', GSI Darmstadt, Stuttgart Dynamitron)
- Heavy ion induced short wavelength laser schemes
- Excimer emssion using ion beam excitation
- Low energy electron beam excitation
  (XUV-, VUV-, UV-lamps, IR-laser)

Concept :



Parameters for low energy electron beam excitation :

Particle energy:	typically 15keV
Foil:	300 nm silicon nitride
Gas:	typically 0.1 to 2 bar
Beam current	cw typ. 10 µA av. (0.15 W) or pulsed

Energy deposition in matter:

Bethe formula

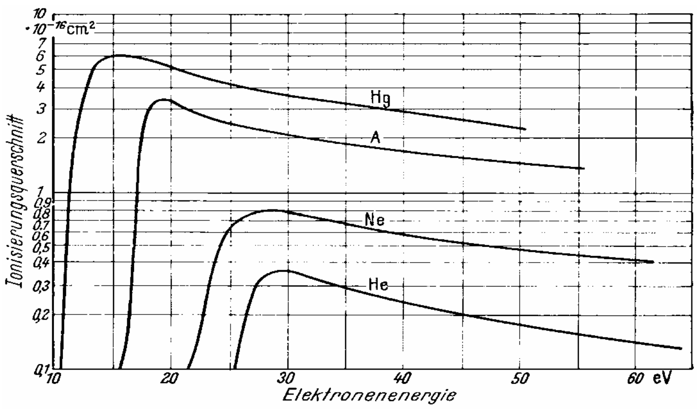
$$\frac{dE}{ds} = \frac{4\pi N Z z^2 e^4}{mv^2}\left[\ln\left(2\frac{mv^2}{I\left(1-\beta^2\right)}\right)-\beta^2\right] \propto \frac{\rho}{E}\ln\frac{E}{I}$$

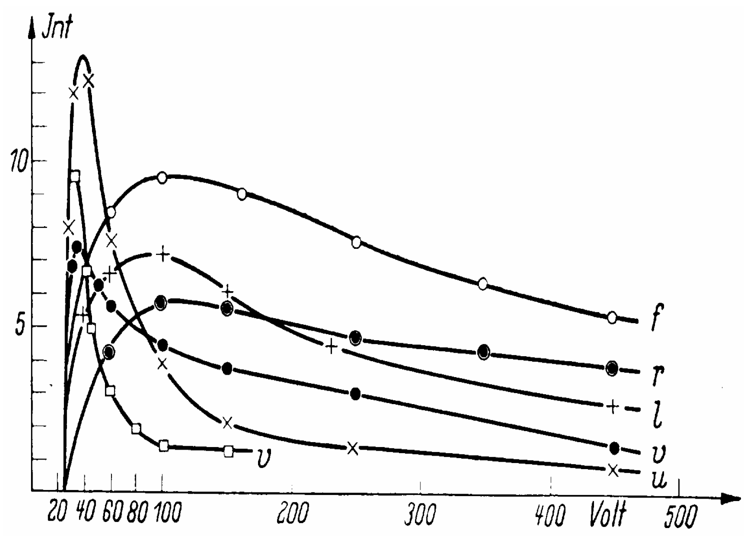
We were always interested in high dE/ds values.

This is achived by high z (heavy ion) projectiles and/or low velocity (low energy electron) projectiles!

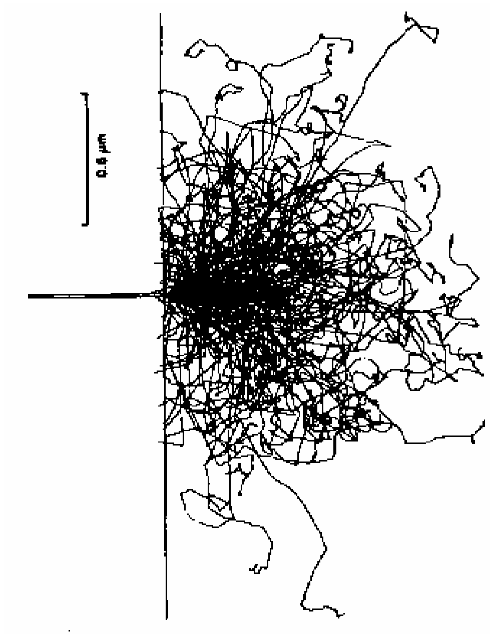
Detailed description at the end of the track:

Ionisation and excitation cross sections:





Spatial distribution of energy deposition



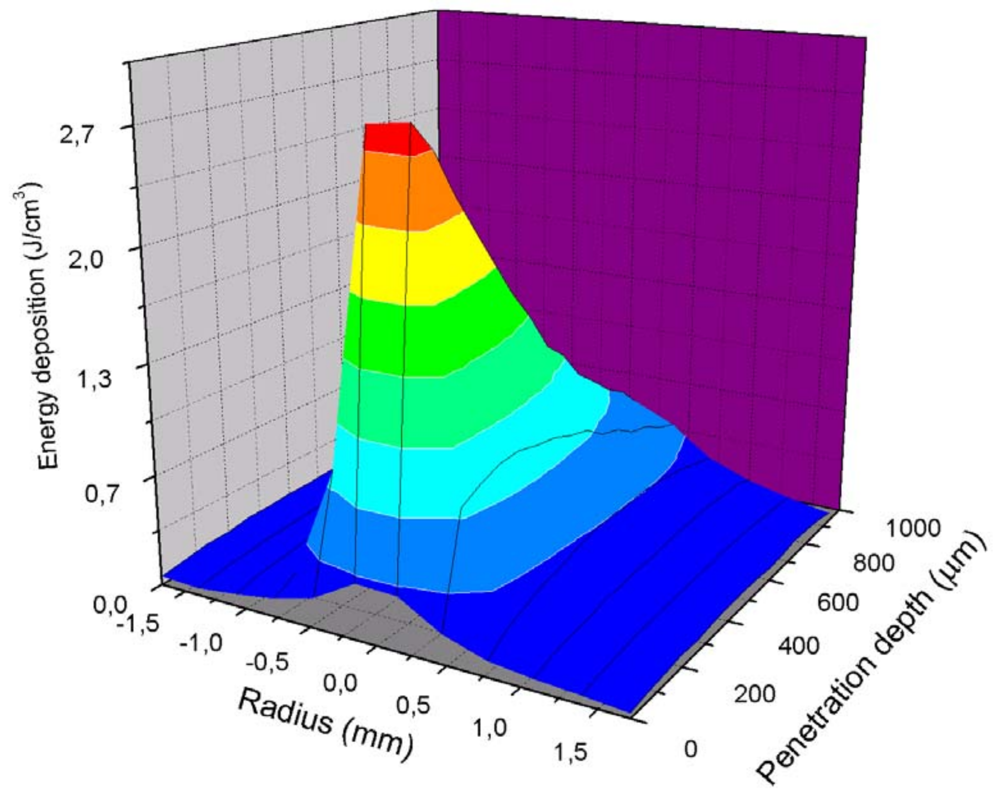
Empirical scaling law for the range r_e (E<50 keV):

$$r_e = \alpha E^n$$

$$\alpha = 6.1 \times 10^{17}/Z, \quad n \approx 1.75$$

E.g.: 10 keV in 1bar Ar: $r_e \approx 0.7\text{mm}$

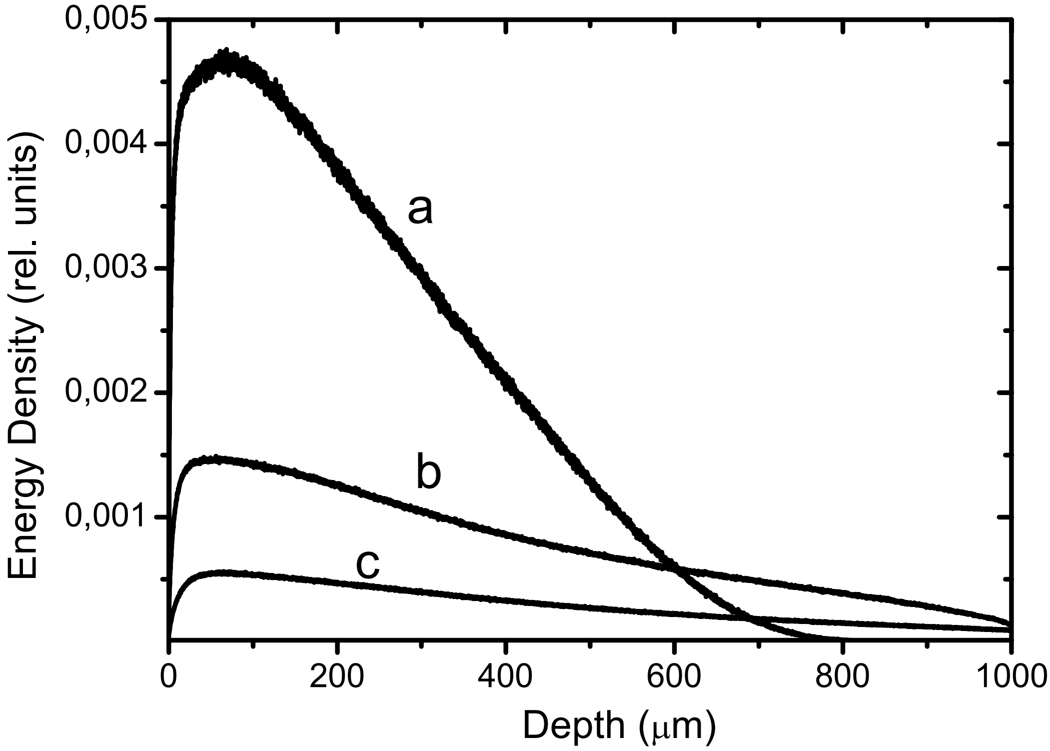
Energy depostion in the gas (1bar Ar)



Modelled using the **"Casino"** Program

P. Drouin, A. R. Couture, R. Gauvin, P. Hovington, P. Horny, H. Demers, Univ. de Sherbrooke, Quebec, Canada (2002)

Energy deposition on the beam axis:

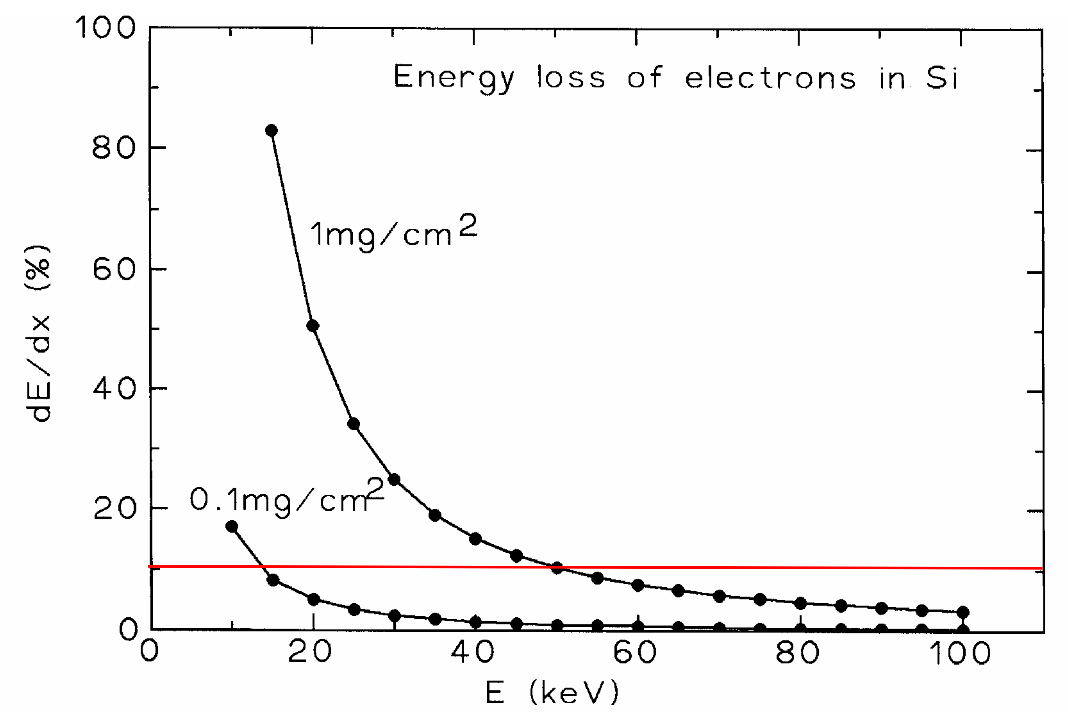


a) 4 bar Ar
b) 1 bar Ar
c) 0.5 bar Ar

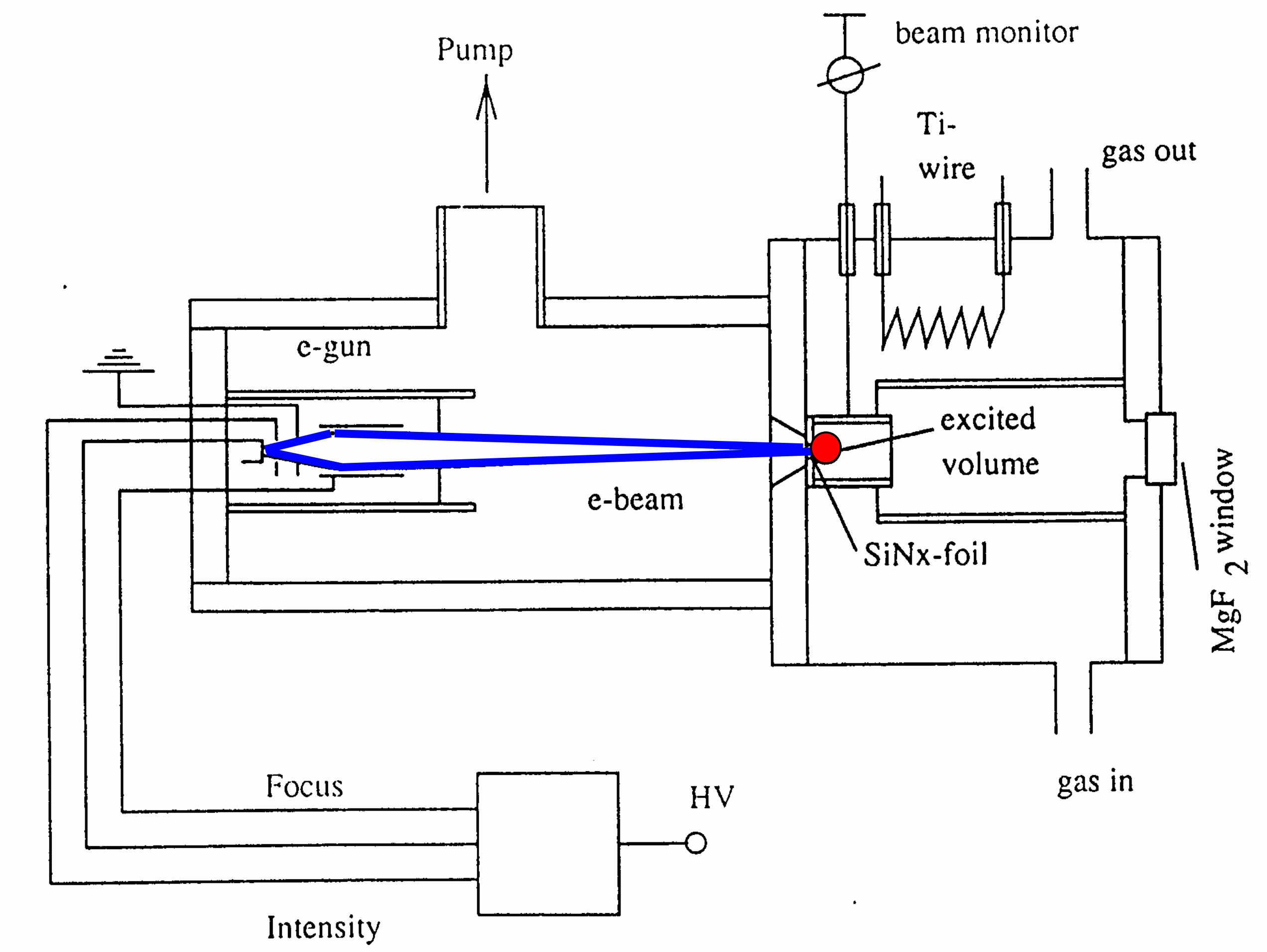
II. Technolgy of low energy electron beam excitation

An 300nm extremely thin SiN_x ceramic membrane is used as the entrance foil for the low energy electrons to be sent into gas targets.

Energy loss of the electrons in the foil:

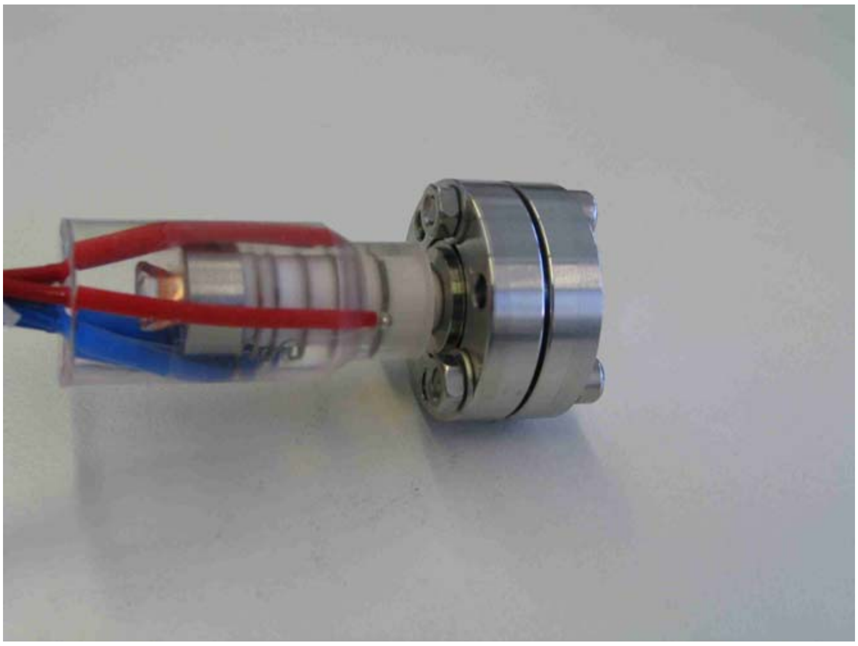


Usage of the membranes: (principle)



Light source development:

Project: TuiLaser AG, THALES Electron Devices, GSF research center, TU- München.
Funded by "Bayerische Forschungsstiftung"



Presently not available in the Unites States of America

Diagnostics and gas system:

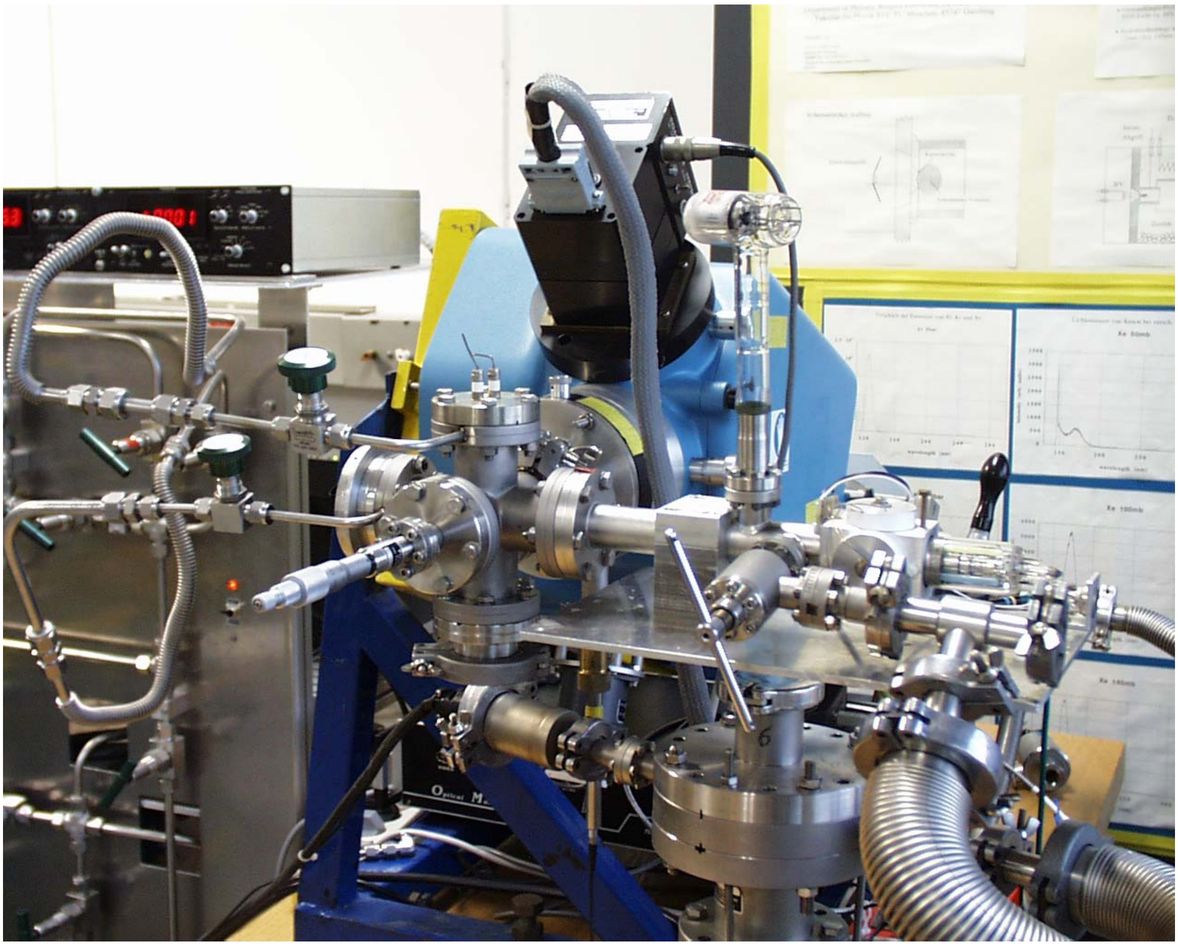
Time resolved optical spectroscopy

Grating monochromators (f=30cm, 0.03nm resolution 1.order)

Wavelength range	~30nm to 700nm
Time resolution	~10ns beam pulses, ~1ns electronic res.
Detectors	VUV-PMT, VUV MCP and diode array
Sensitivity measurements:	two WI-17G Lamps (OSRAM)
and	D_2 arc-lamps (Cathodeon)
Gas pressure	0 to ~ 2 bar (foil: 10 bar)

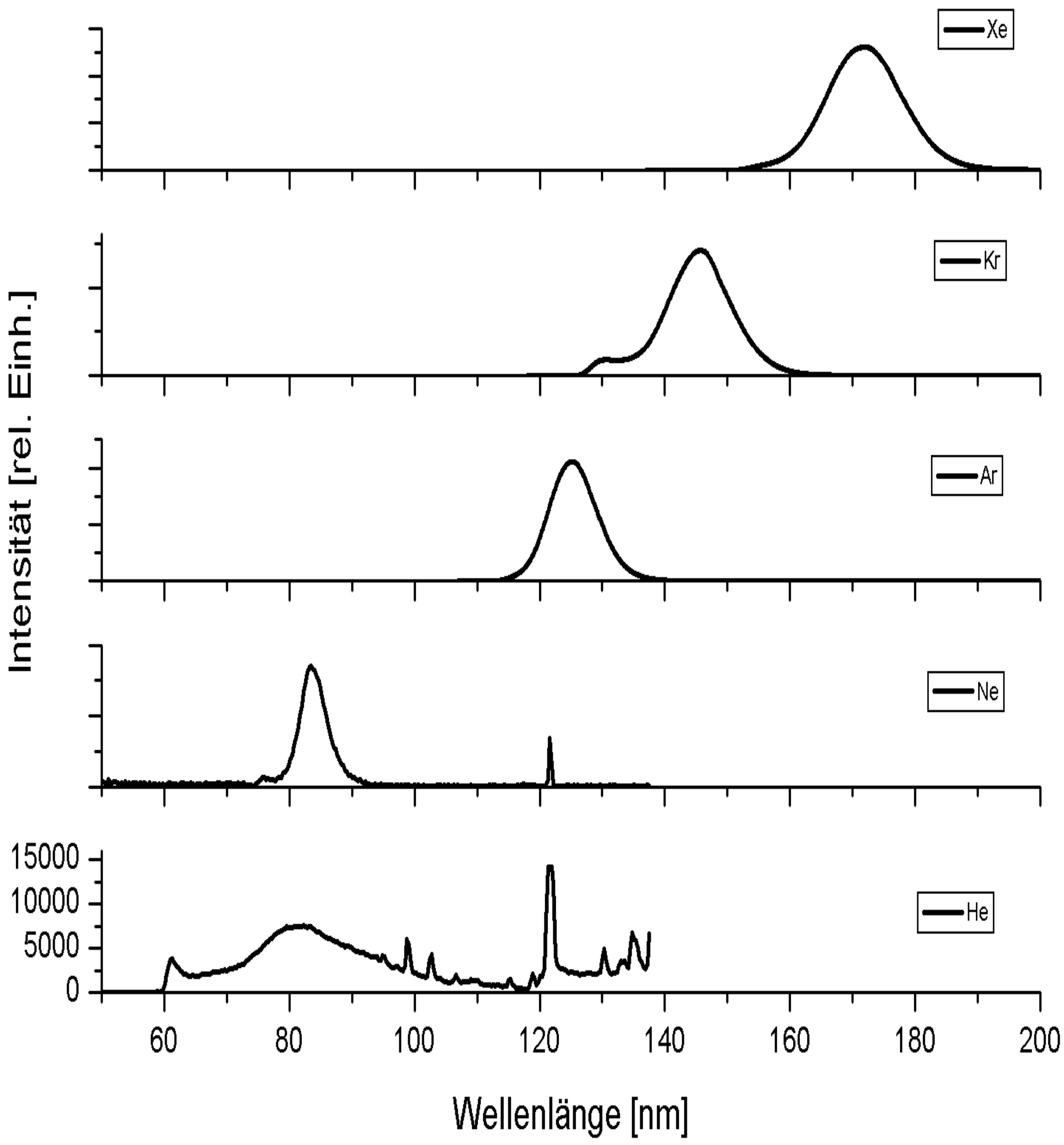
Gas mixing system with hot-metal gas purifiers (rare gases)

Capacitive manometers (MKS Baratron)



Rare gas excimer emission spectra:

Gas pressures: ~ 1bar



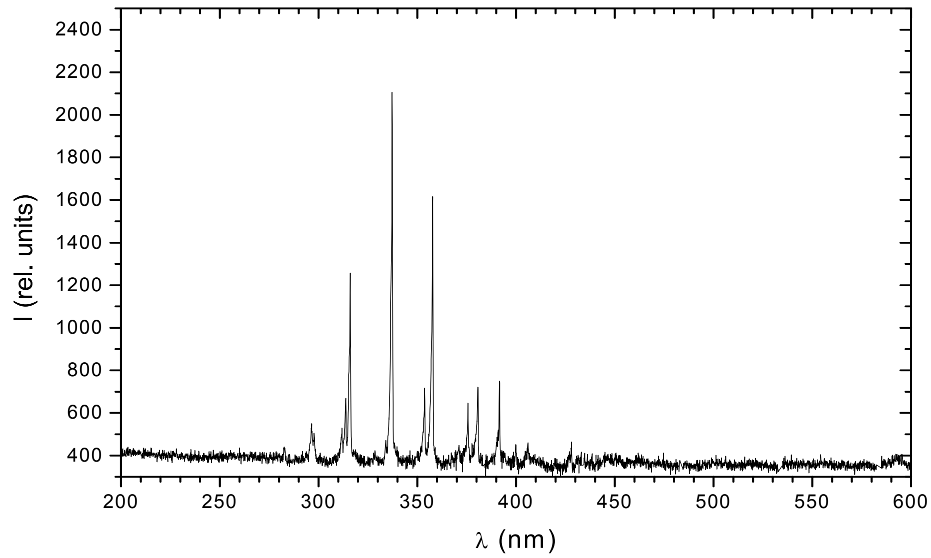
Efficiency: up to 40%

Wavelength range: 60 to 200nm

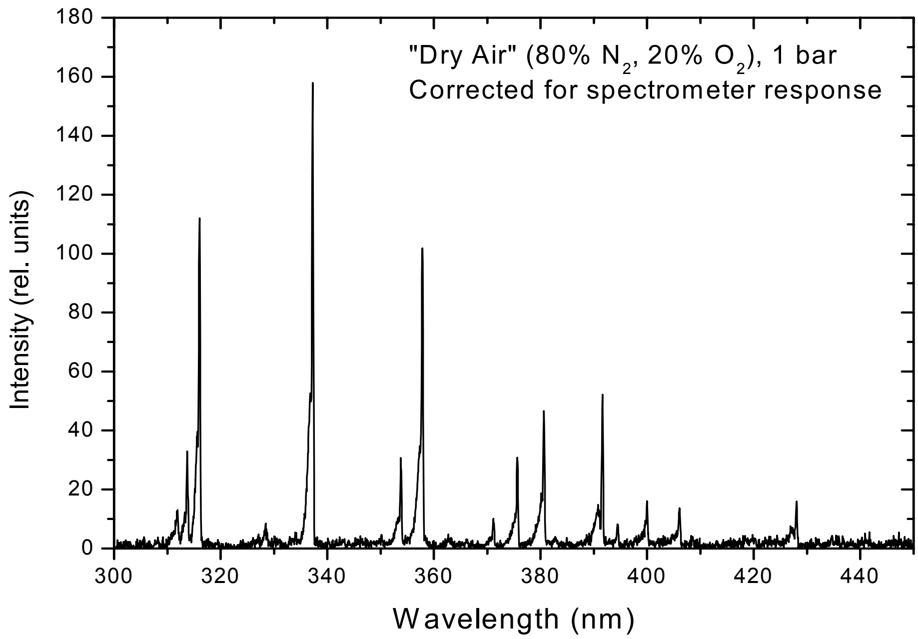
III. Preliminary results from air

Spectra:

Overviev, 1bar, ~ 12keV electron beam excitation

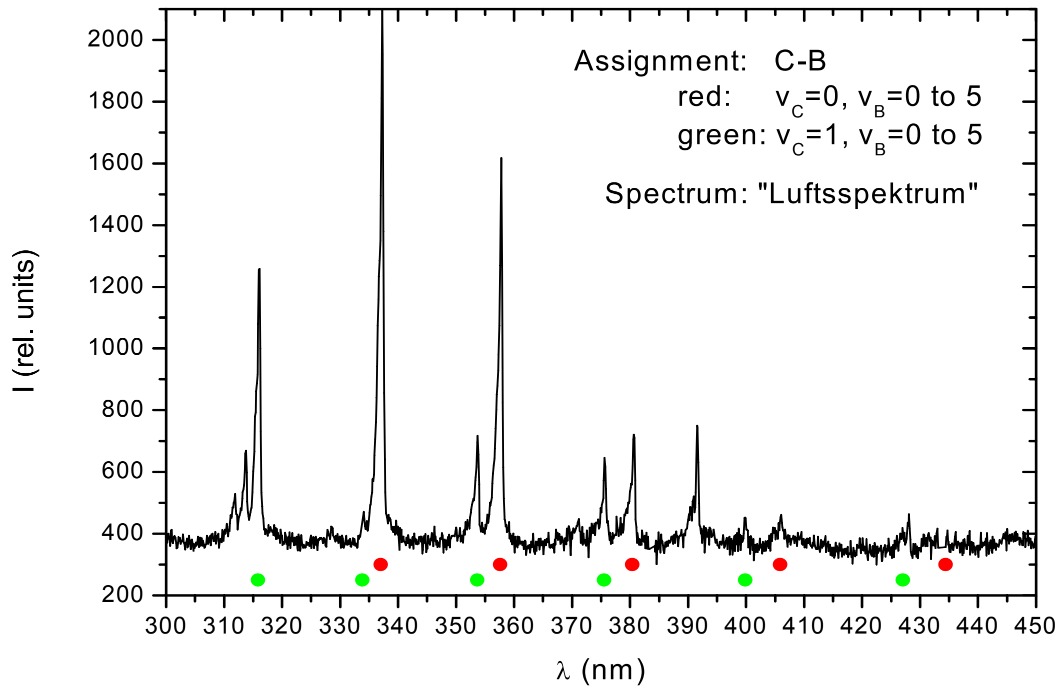


Expanded view 300-450nm:



Preliminary result. Needs to checked!

Assignment:



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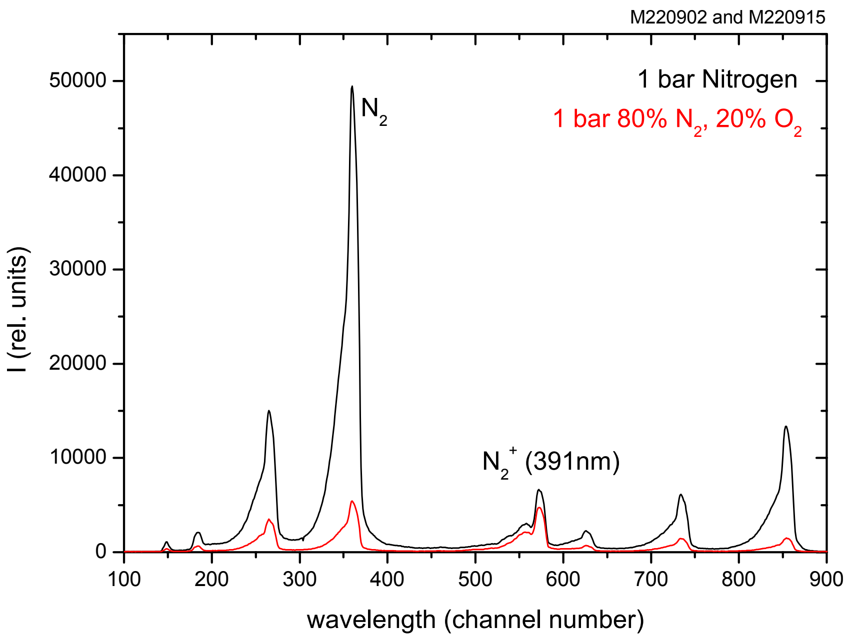
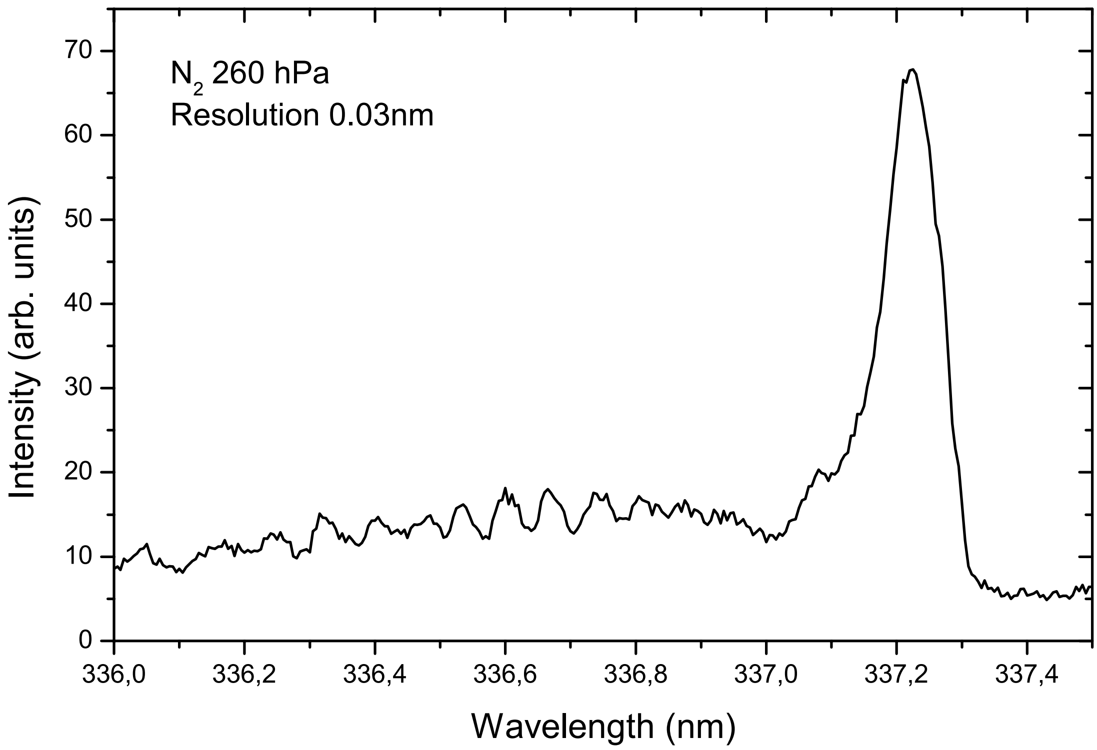
he band around 391nm is from N_2^+ (B-X)

Pure nitrogen versus "artificial air" (80% N_2, 20% O_2)

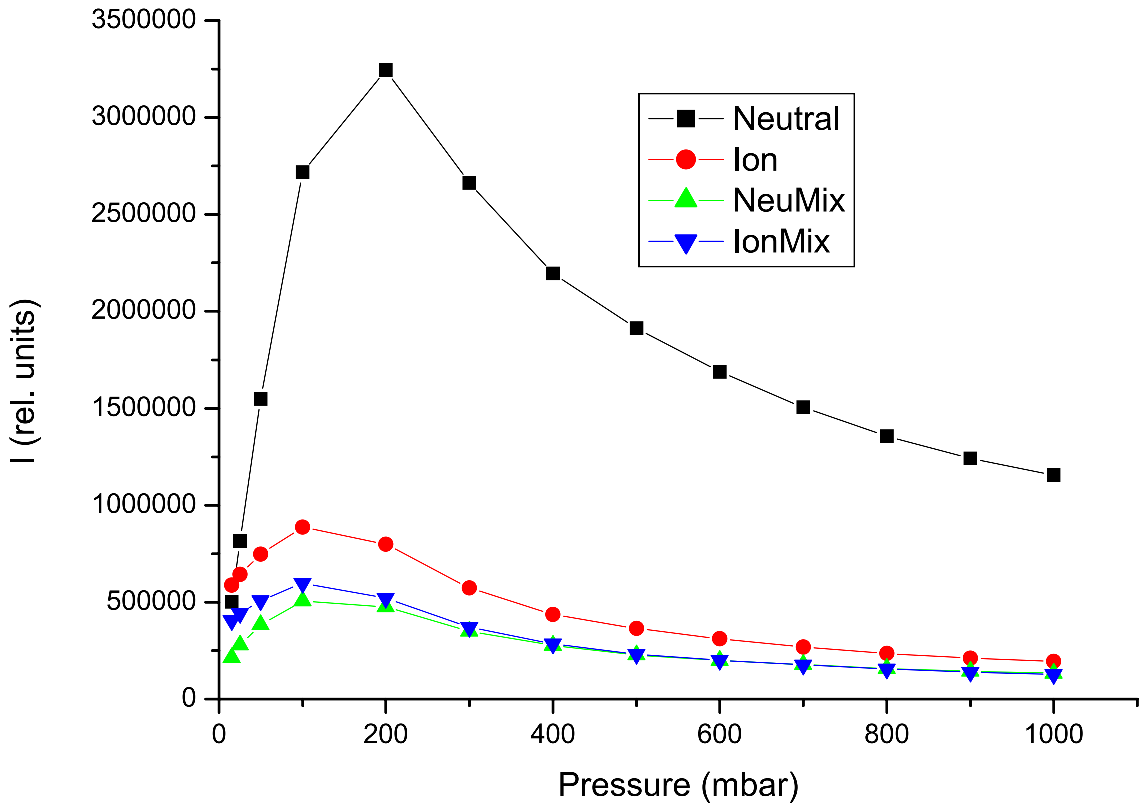


High resolution spectrum:



Pressure effects

Trend in the 337nm (N_2) and 391nm (N_2^+) bands:

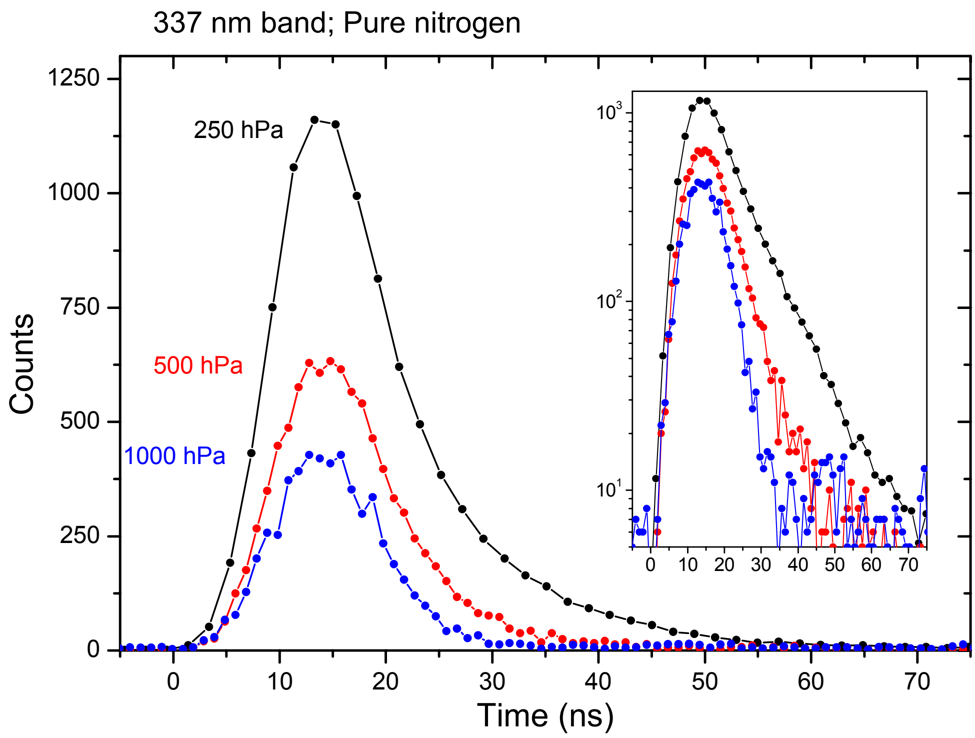


Comment: The intensity reduction towards low pressure below 200mbar is mainly due to geometry effects.

Gas kinetics:

Population and depopulation of an upper level:

$$\frac{d[n^*]}{dt} = \sigma[n]j + \sum k_i [n_i^{**}] - \sum A_{ik}[n^*] - \sum k_q [n_q][n^*]$$

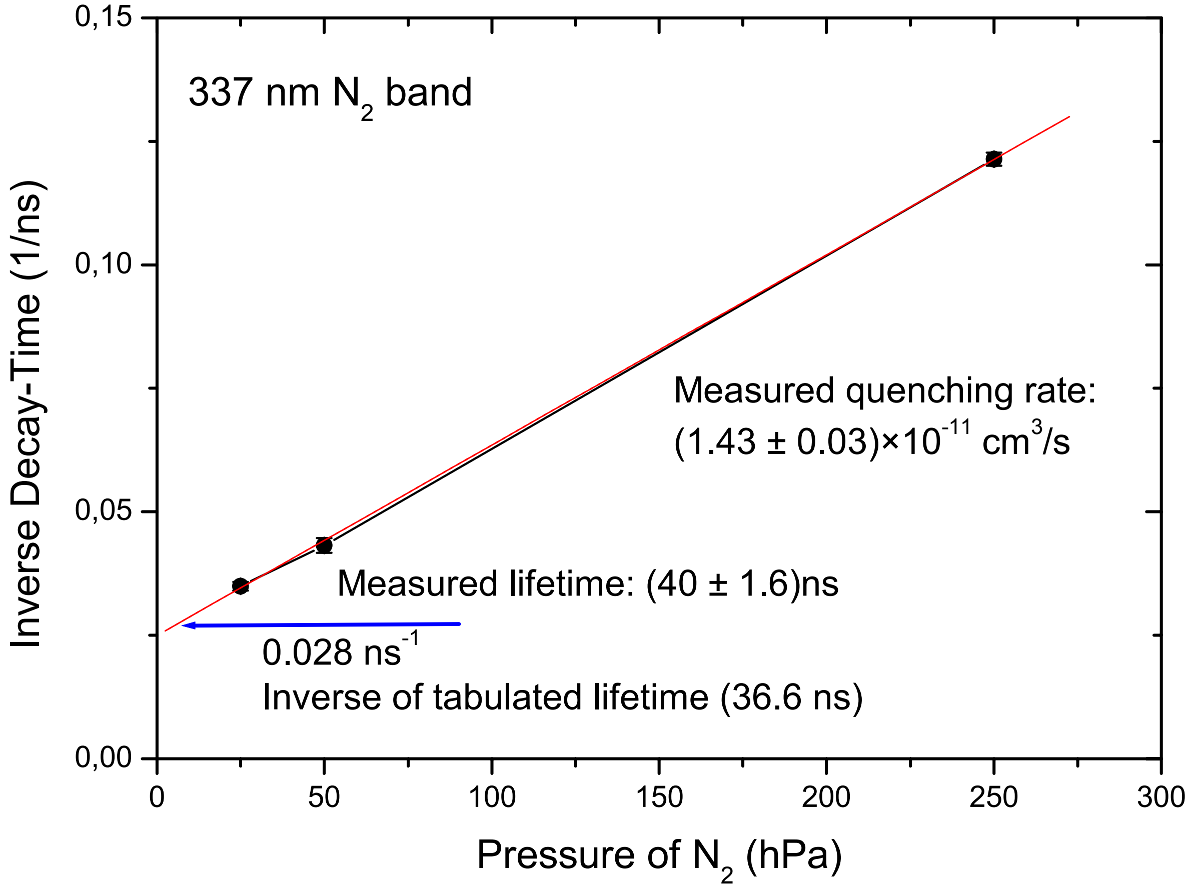


After the excitation pulse (no cascades):

$$\frac{d[n^*]}{dt} = -\sum A_{ik}[n^*] - \sum k_q [n_q][n^*]$$

This leads to an exponential decay of light intensity

Example: self-quenching of N_2



Similar measurements can be performed for N_2 quenching by oxigen or water vapour adding various partial pressures of O_2 or H_2O, respectively!

An Ar-N_2 mixture (94% Ar, 6% N_2) gives ~ 2% conversion efficiency from e-beam power into N_2 light output into 4π (0.4% into the 337nm band (~ 20% of total light)).

The influence of humidity on output intensity has been measured.

Conversion efficiency:

Intensity ratios in the emission bands

from relative calibration of the monochromator response, normalized to the strongest 337nm N_2 band:

Preliminary!!! Calibration needs to be verified!!!

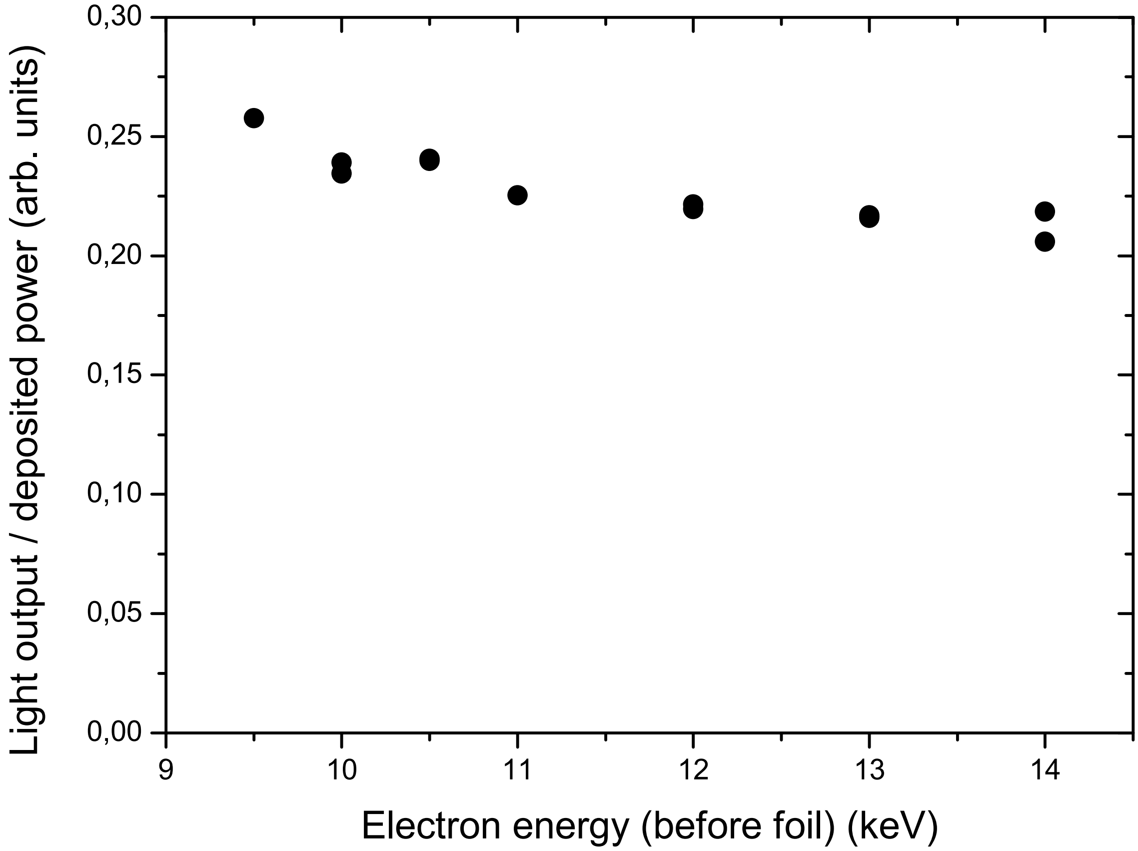
Dry "artificial air" 80% N_2, 20% O_2, 1 bar

λ (nm)	I_n/I_{337nm}
312	0.11
314	0.19
316	0.65
"316" total	0.95
337	1
354	0.19
358	0.72
371	0.05
376	0.20
380	0.33
391	0.34
394	0.04
400	0.12
406	0.10
427	0.13

The linearity of light intensity with beam current has been measured.

Scaling of light output with electron energy:

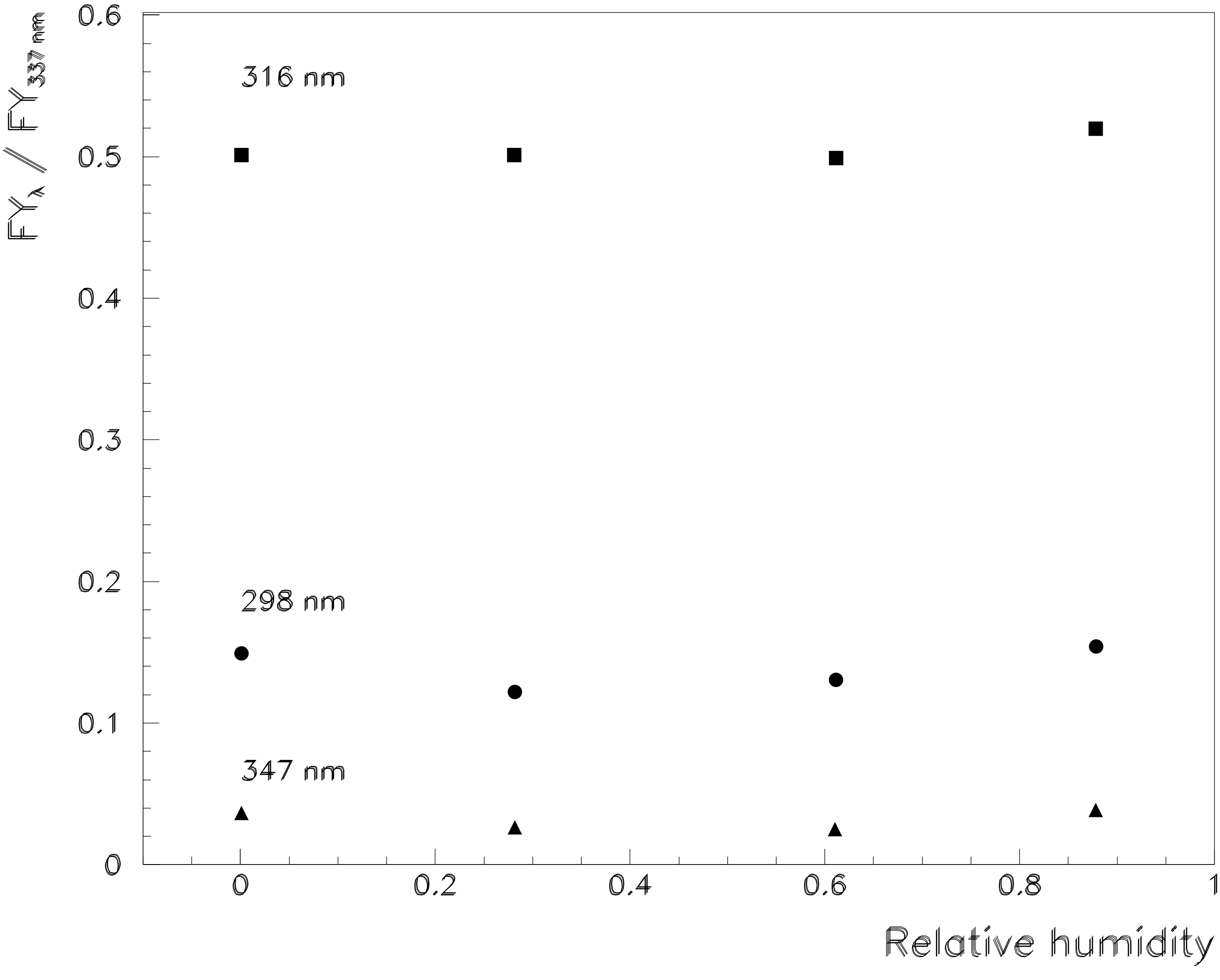
Electron beam power has been determined using the “Casino” Monte Carlo program:



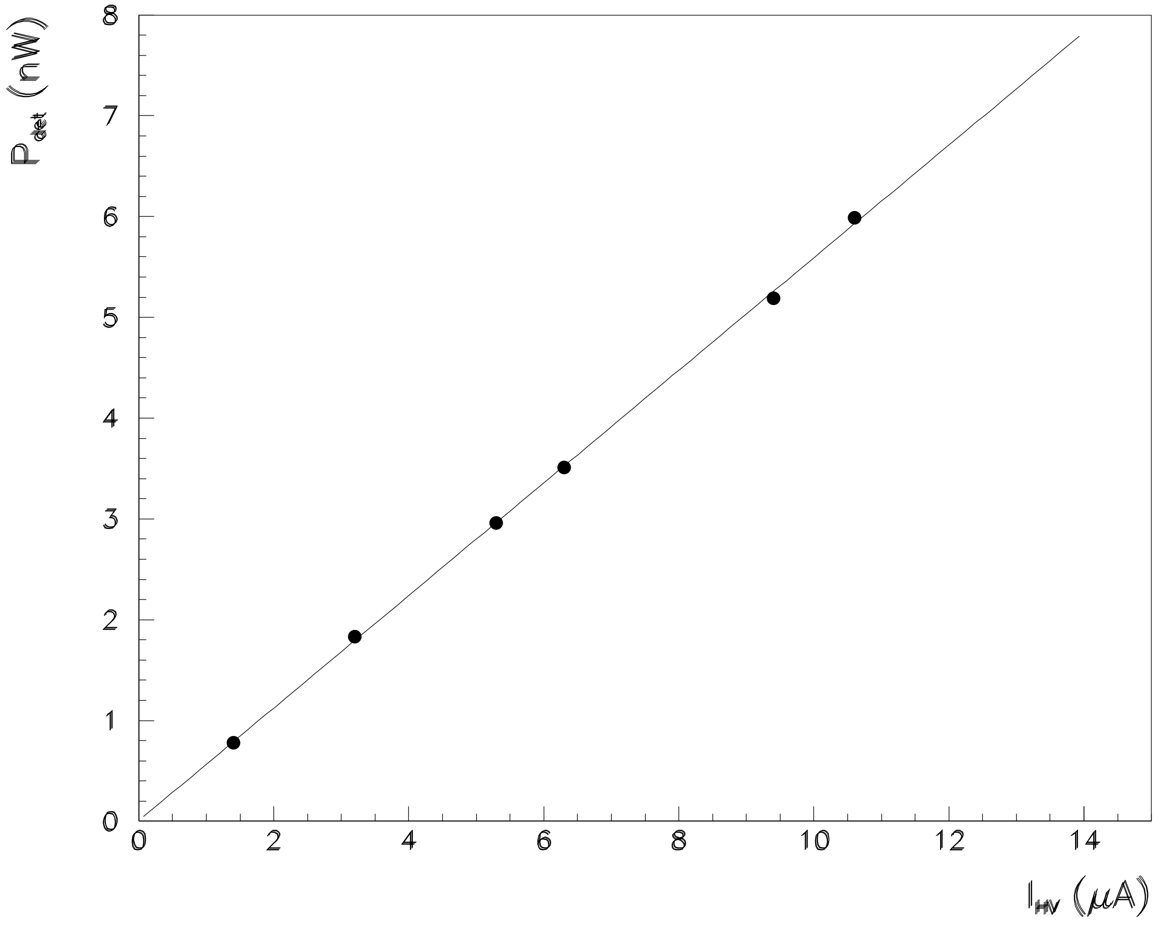
Absolute yield (preliminary result): 2.45×10^{-5}

(comment: This is light output divided by beam power)

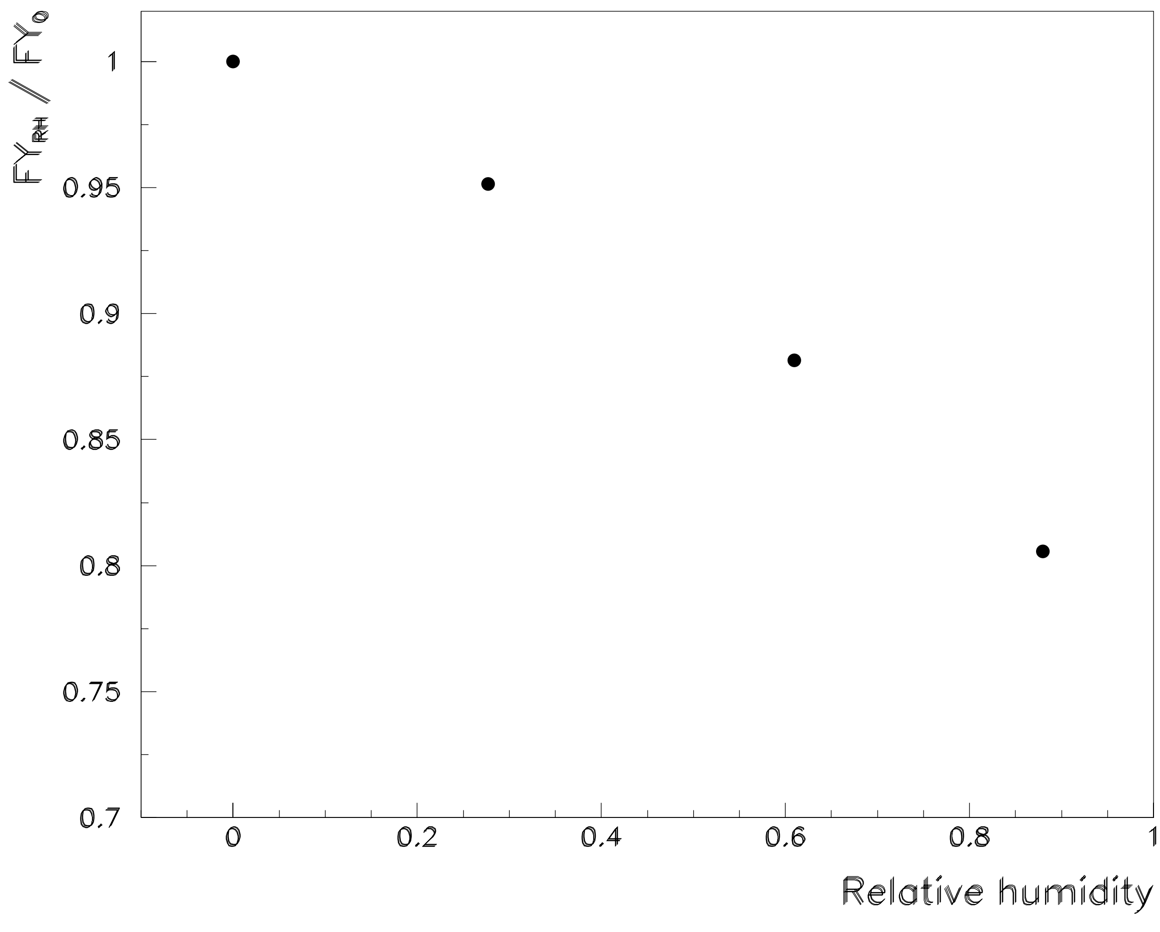
Temperature effects are to be measured



$FY_\lambda / FY_{337\,nm}$
316 nm
298 nm
347 nm
0
0.1
0.2
0.3
0.4
0.5
0.6
0
0.2
0.4
0.6
0.8
1
Relative humidity



P_{det} (nW)
I_{HV} (μA)



FY_{RH} / FY_0
Relative humidity