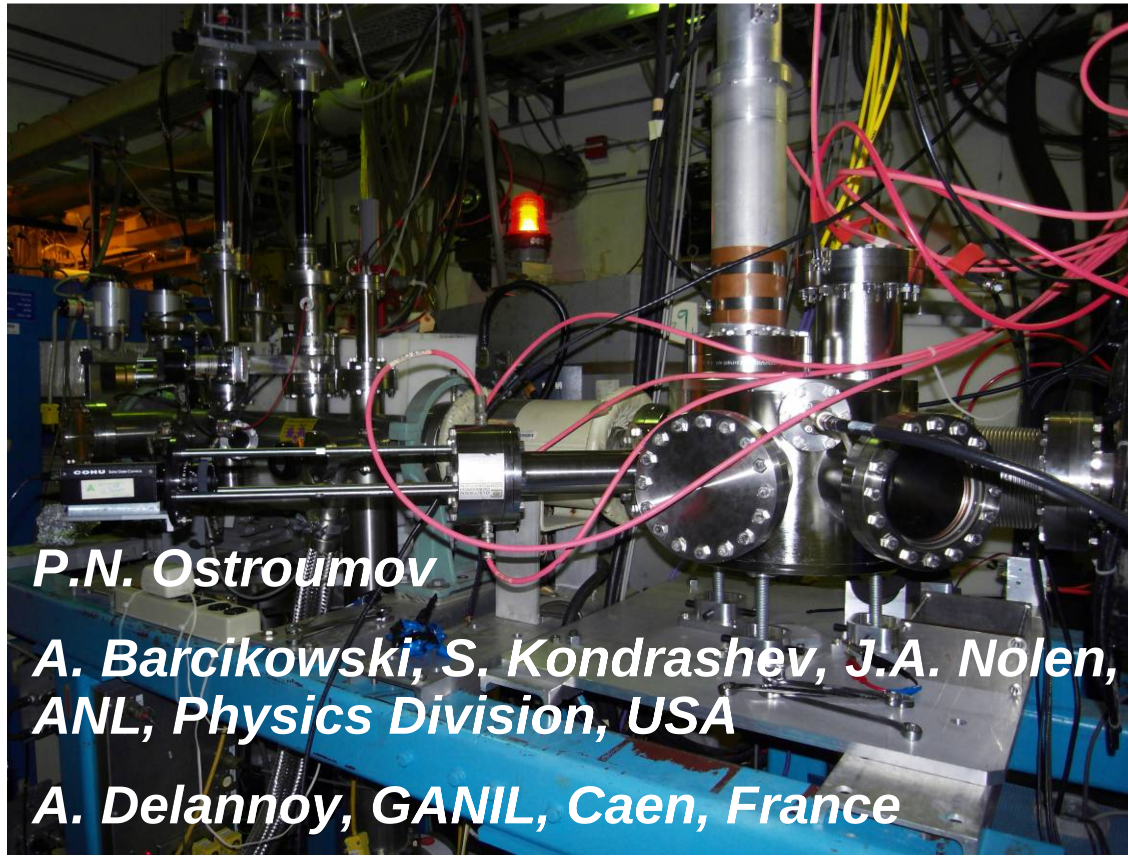
BUNCH LENGTH DETECTOR BASED ON X-RAY PRODUCED PHOTOELECTRONS



P.N. Ostroumov

A. Barcikowski, S. Kondrashev, J.A. Nolen, ANL, Physics Division, USA

A. Delannoy, GANIL, Caen, France

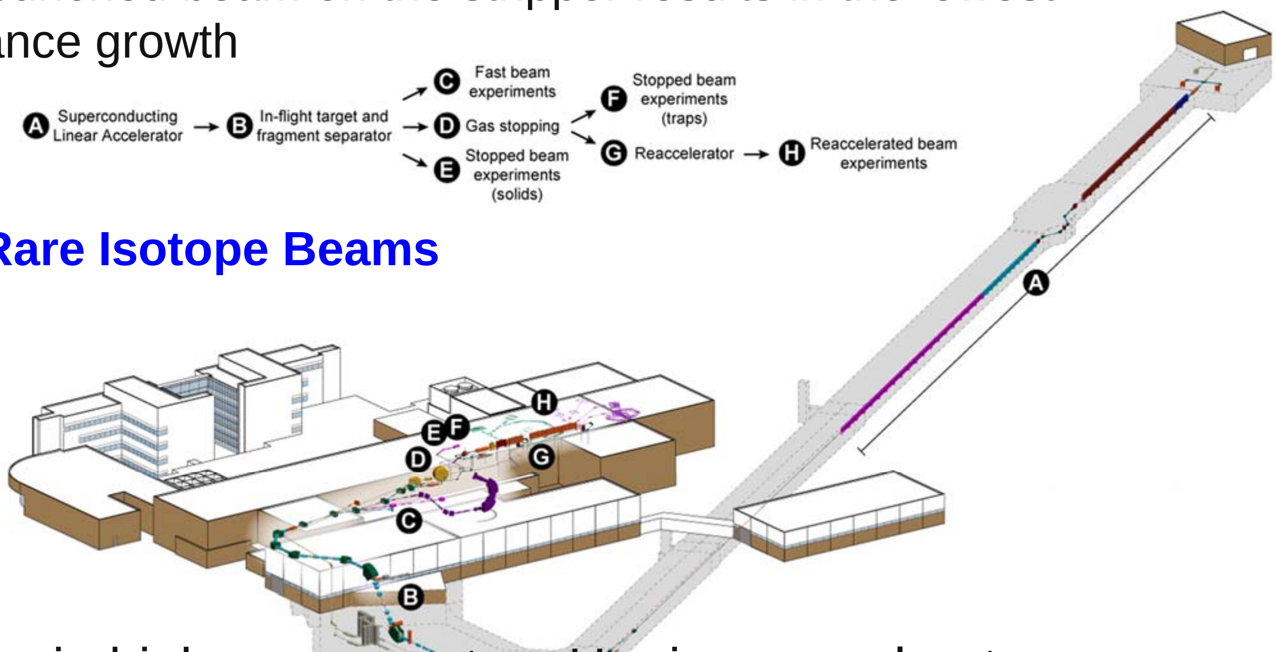
Particle Accelerator Conference, May 3-8, 2009

Content

- Motivation
- Properties of X-rays produced due to the interaction of proton/ion beams with material
- Bunch length detector based on X-ray produced photoelectrons
  - Principle of operation
  - Photocathode
  - Registration of photoelectrons
- Experimental results, bunch shape of ion beams
- Possible modifications of the detector for application in high-power accelerators

Motivation

- Stripping of heavy-ion beams in high-power driver accelerators
  - time focus of the bunched beam on the stripper results in the lowest longitudinal emittance growth
  - Application:



FRIB – Facility for Rare Isotope Beams

- X-BLD for application in high-power proton, H-minus accelerators
  - Does not require wire or target permanently inserted into the beam. A gas flow can be used
  - Bunch longitudinal profile can be monitored on-line which is not possible using conventional methods

Properties of X-rays from the target

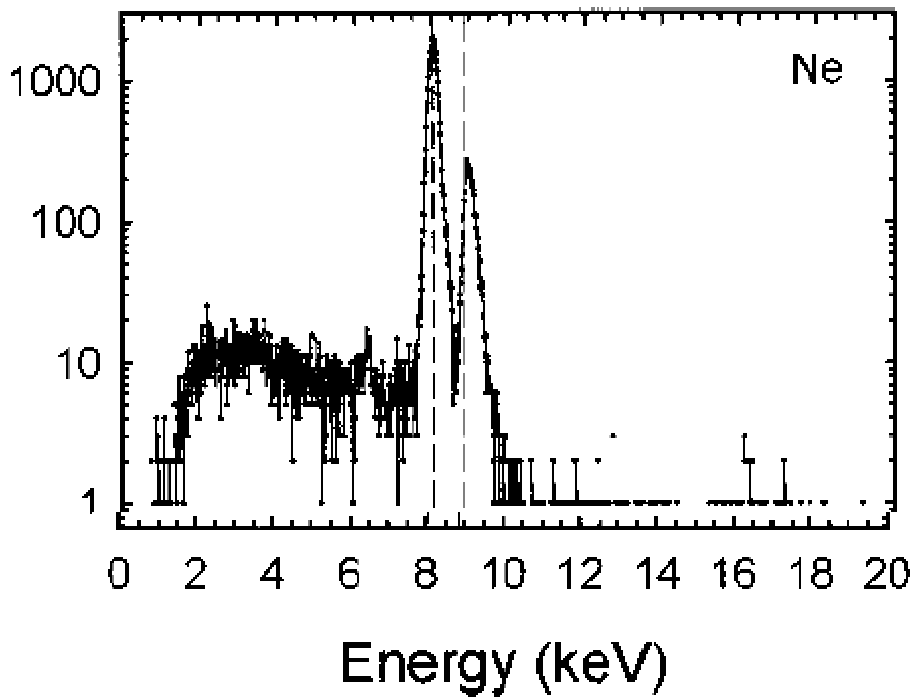
K-SHELL IONIZATION IN HEAVY-ION COLLISIONS

W. E. Meyerhof [1]

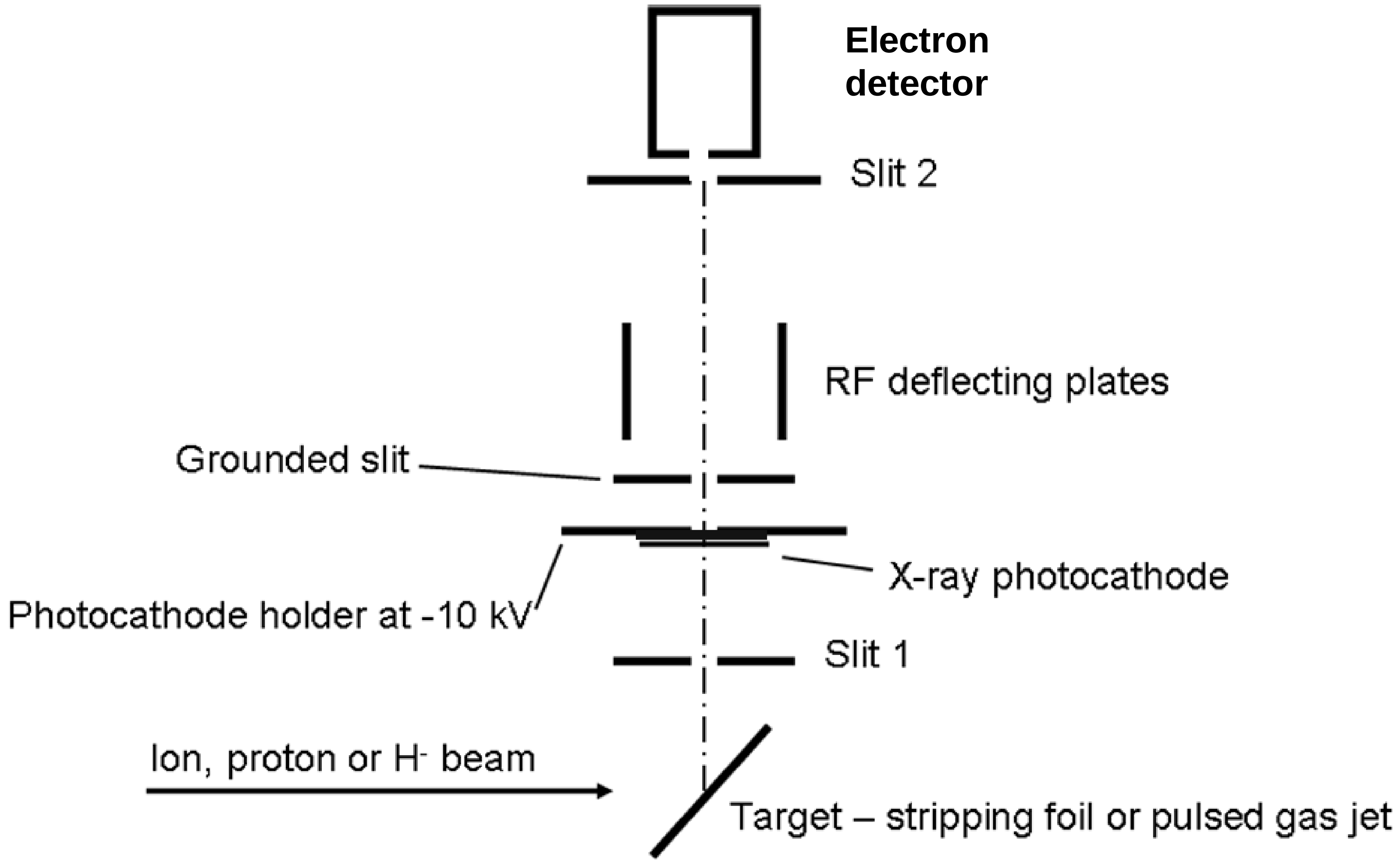
10^{-19} sec. On the other hand, typical decay times for *K*-shell vacancies are of the order of $10^{-10}/Z^4$ sec (27), which for Br is $\sim 10^{-16}$ sec. Since the outer electrons

- Potentially can provide resolution of several picoseconds
- Intensity of K-shell X-rays is 2 order of magnitude higher

- For test purpose at low-intensity ion linac we use copper target
- For high-intensity beams: use, for example, xenon gas flow



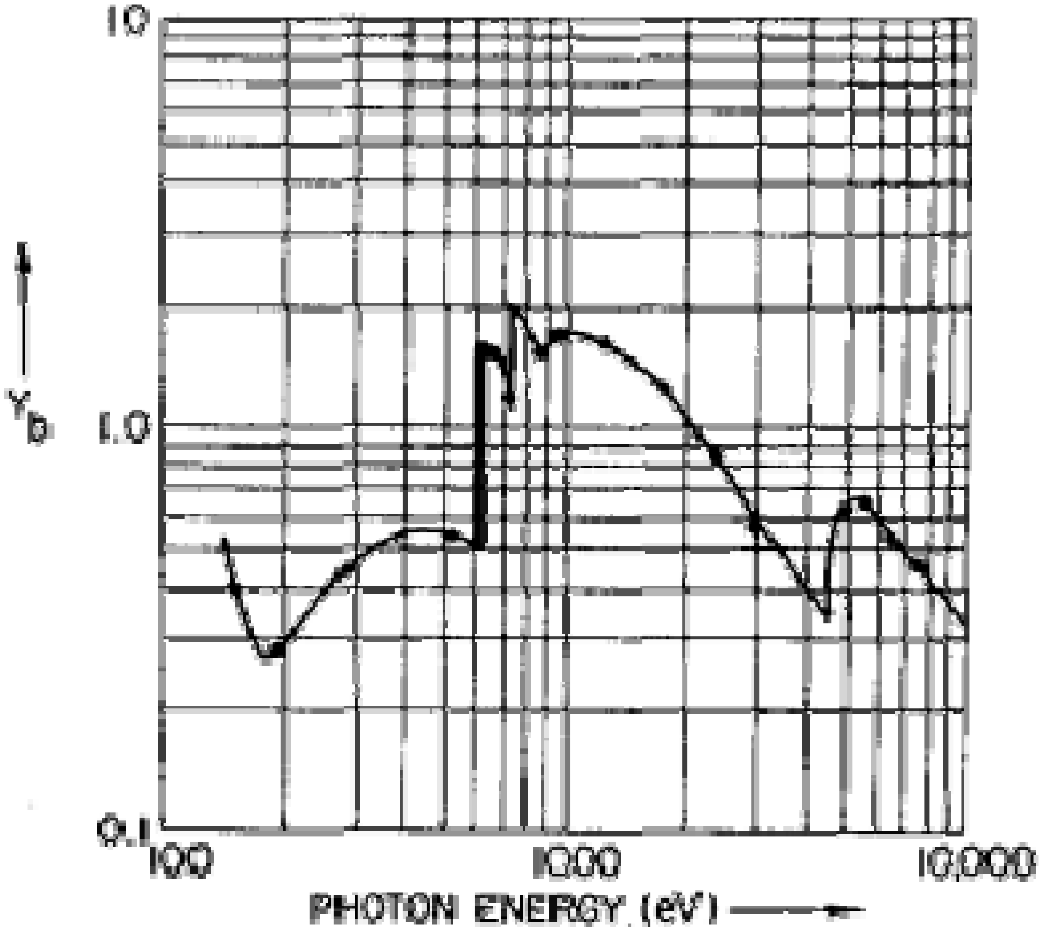
X-ray based bunch length detector: principle of operation



Photocathode

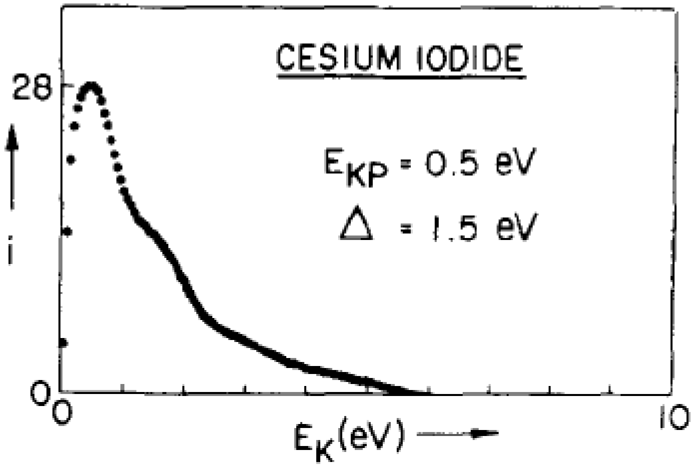
Back-surface secondary electron quantum yield for a 1020-Angstrem CsI transmission photocathode

- The best response of the photocathode is with 1 kV X-Ray

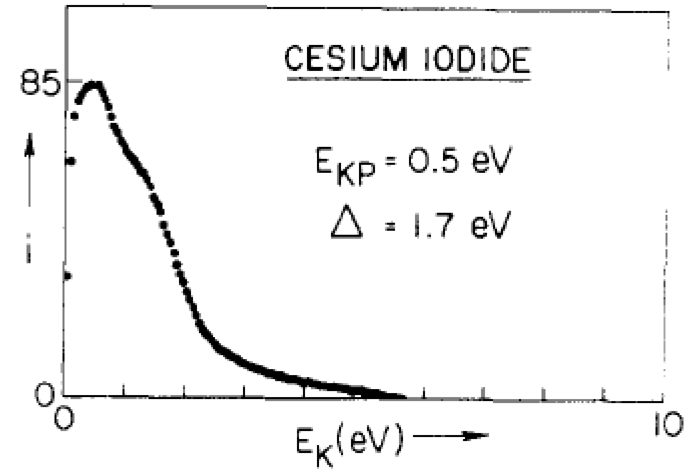


Photocathode – Properties of photoelectrons

Energy distribution of the photoelectrons:



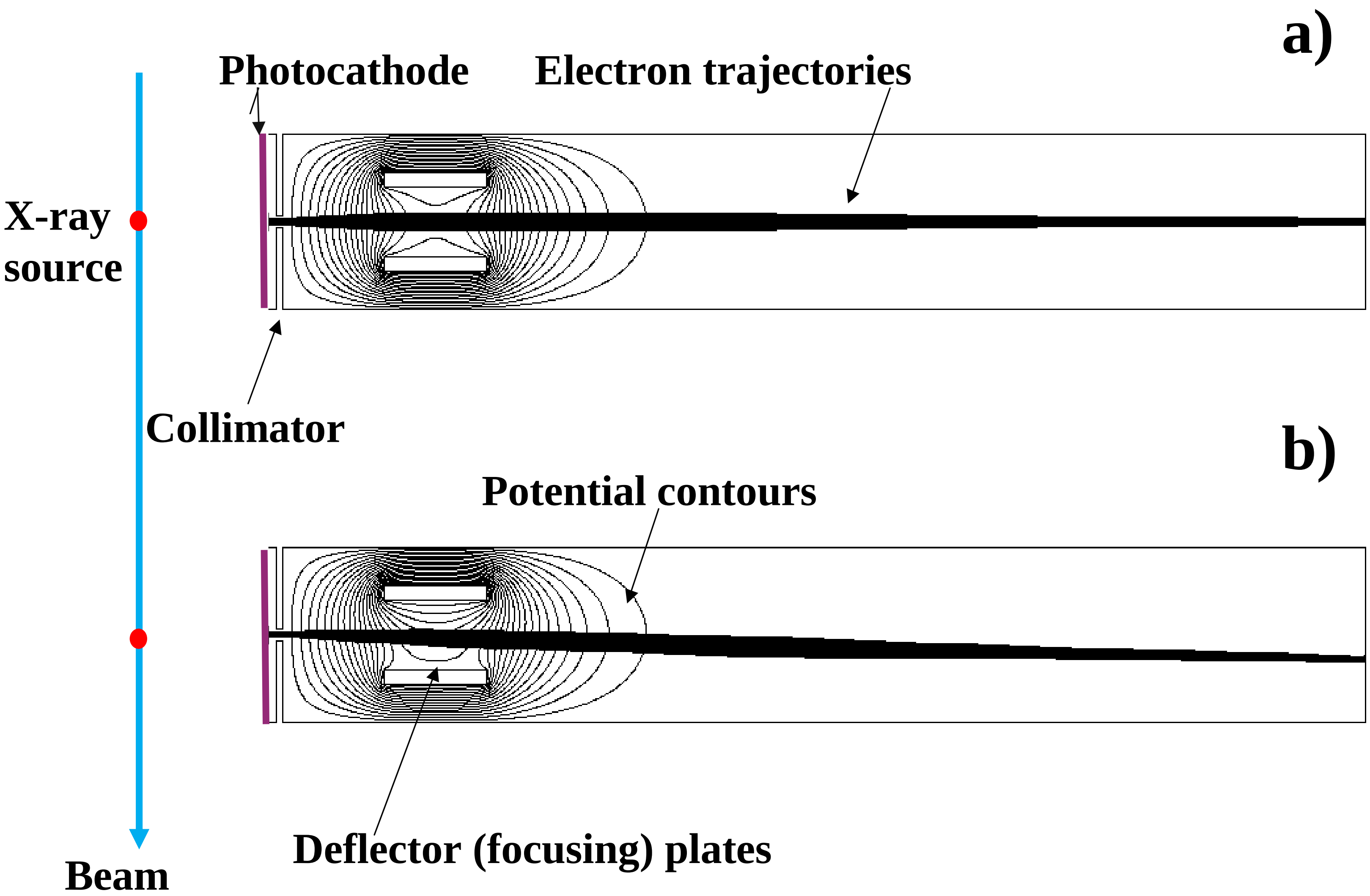
Photoelectron energy distribution for CsI photocathode excited by X radiation with an energy of 277 eV.



Photoelectron energy distribution for CsI photocathode excited by X radiation with an energy of 8080 eV.

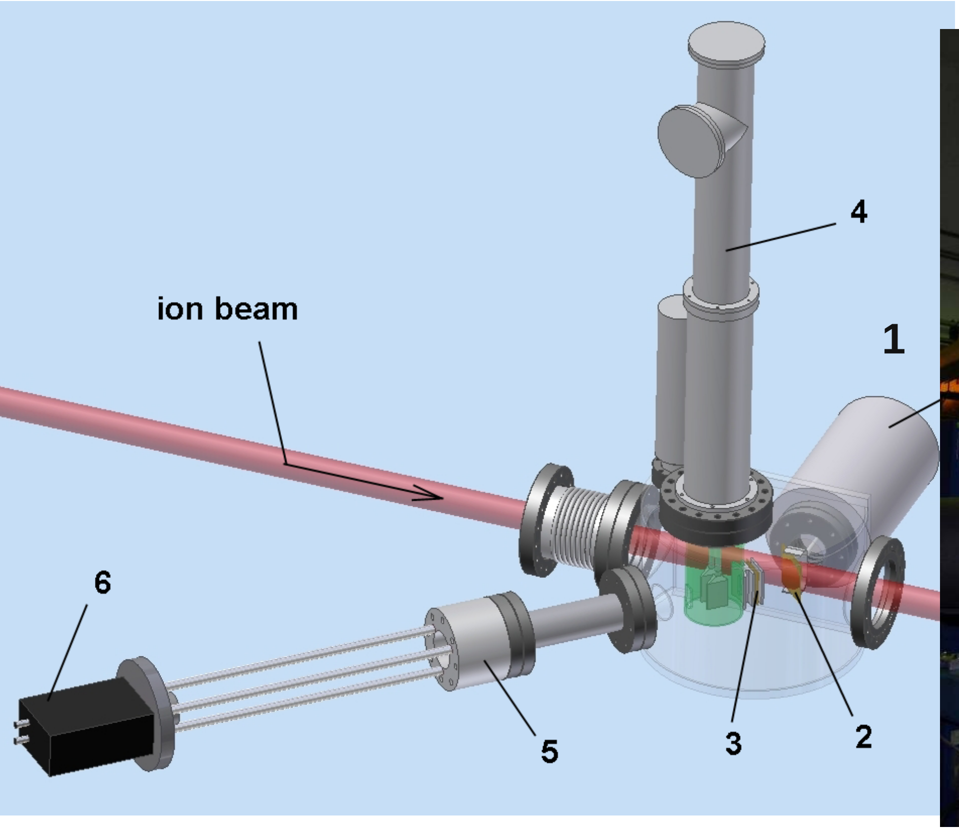
- **the both distributions are almost the same with a peak at 0.5 eV**
- **nearly the same width at half maximum.**
- **80% of the photoelectrons are below 2 eV.**

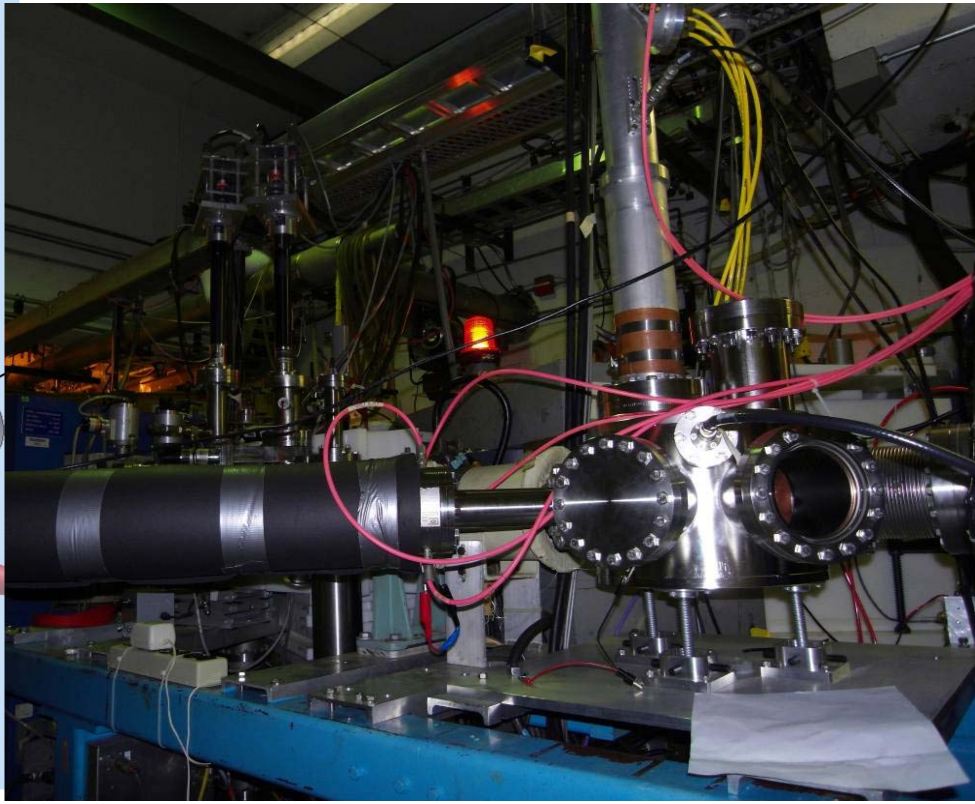
Trajectory of photoelectrons



X-ray based BLD (Argonne National Laboratory)

- General view of the X-BLD installed at the ATLAS facility. 1 – target translator, 2 – target, 3 – photocathode assembly, 4 – RF deflector, 5 – detection unit, 6 – CCD-camera.





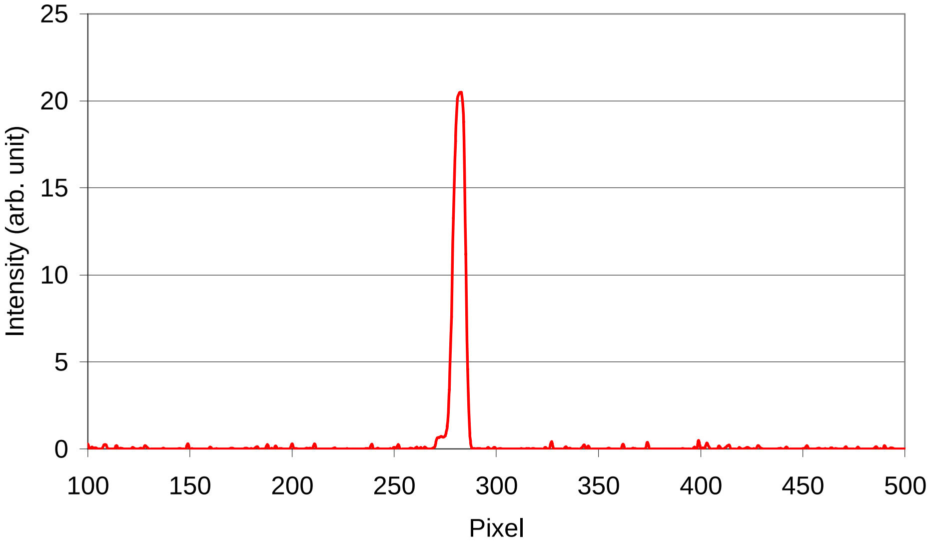
Commissioning of the detector

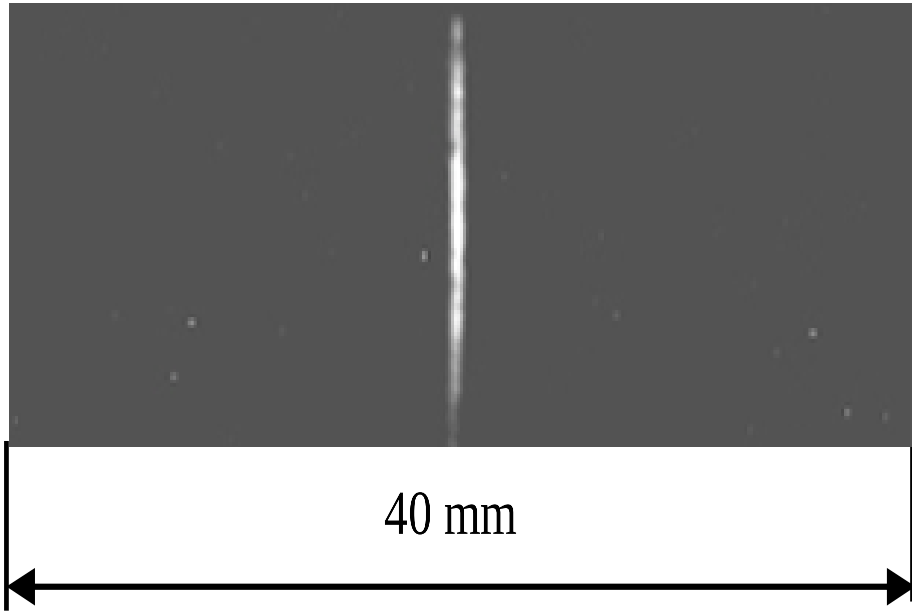
- The slit downstream of the photocathode was too wide (1 mm)
  - Reduced to 0.15 mm
- Stray magnetic field steers 10 kV electrons
  - Shielding against magnetic field
- RF frequency of the deflector is 97 MHz and is driven by the Accelerator master oscillator
- Improve the optics of the BLD to obtain better focusing on the phosphor screen, additional electrostatic steering and focusing was added
  - With 0.15 mm slit additional focusing and steering is not required
- Primary ion beam must be tuned to avoid losses on the walls
  - Can produce X-rays on the walls which increases the background
- Chevron MCP
  - Very good amplification, up to 10^8
  - Problem: Narrow dynamic range, Dynamic range depends from amplification
- Most problems due to very low intensity of primary beam in our facility
  - Beam current is below 0.5 μA

Electron beam image on the phosphor with no RF applied

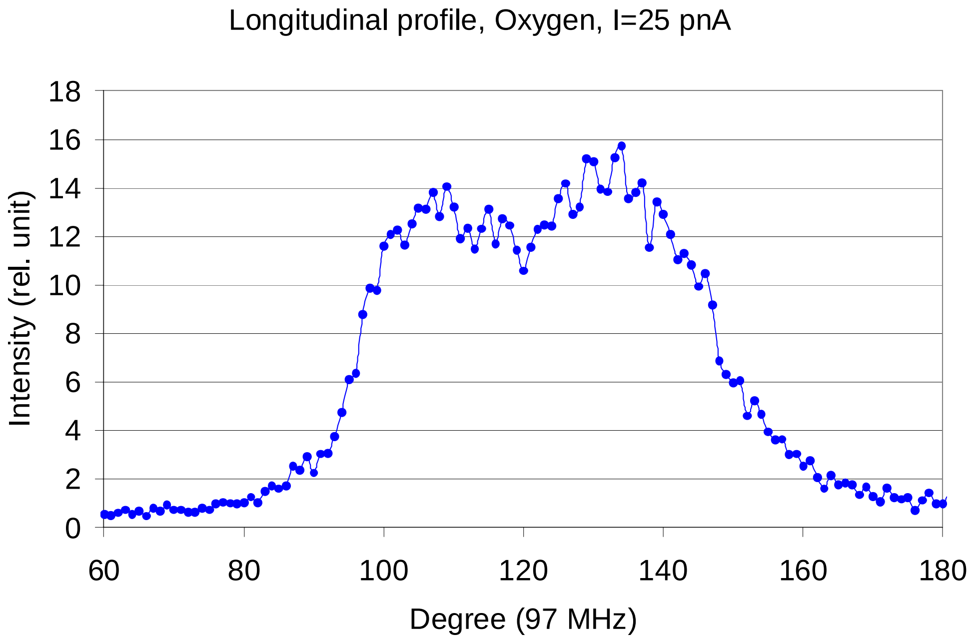
- We installed a slit (0.15 mm) downstream of the photocathode

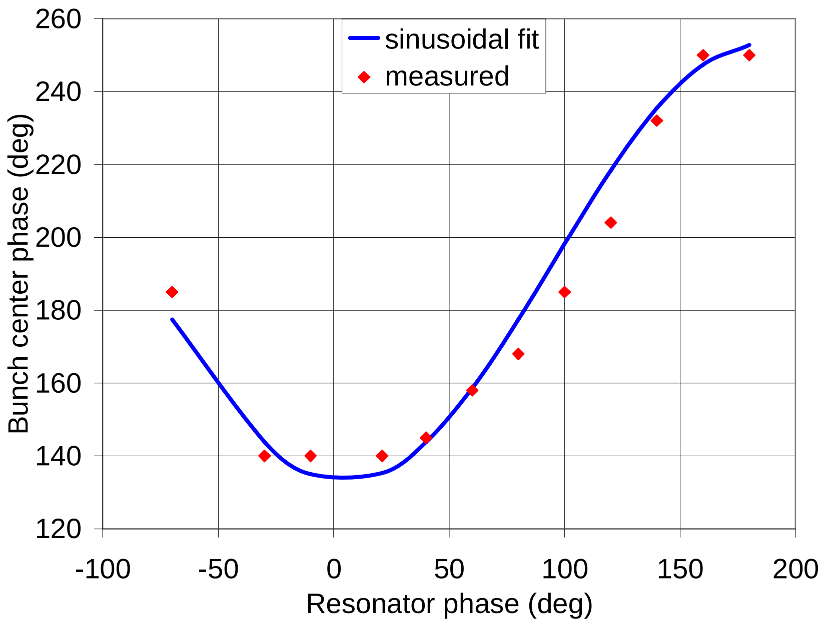
Focused electron beam profile: Resolution is ~5 pixels = 0.4 mm

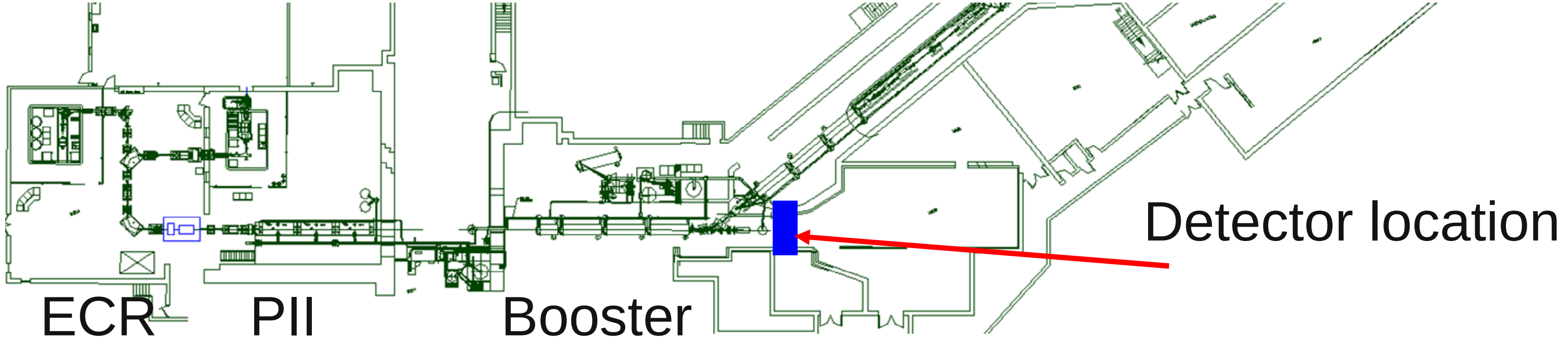




Oxygen beam (~1.6 MeV/u, 9 MeV/u, 0.2 to 0.5 μA)







Bunch Length Detector based on secondary electrons

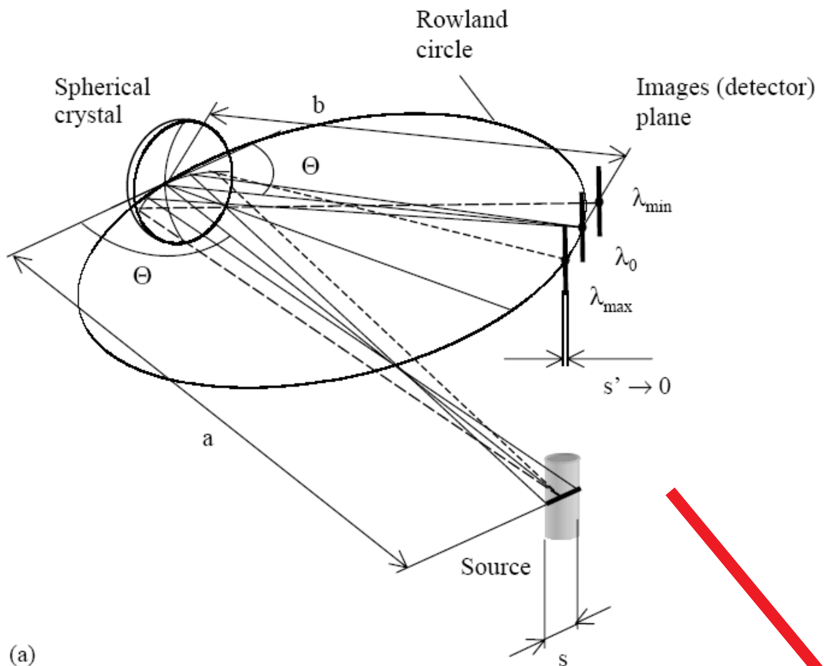
- Very well established technology for proton, H-minus, ion linacs
- Requires a wire biased to -10 kV to produce and accelerate secondary electrons
- Limited beam pulse length (~50 to 150 μsec) and beam repetition rate to avoid destruction of the wire
- Proton beam space charge and magnetic field can impact on electron trajectory – requires more studies for high current beams

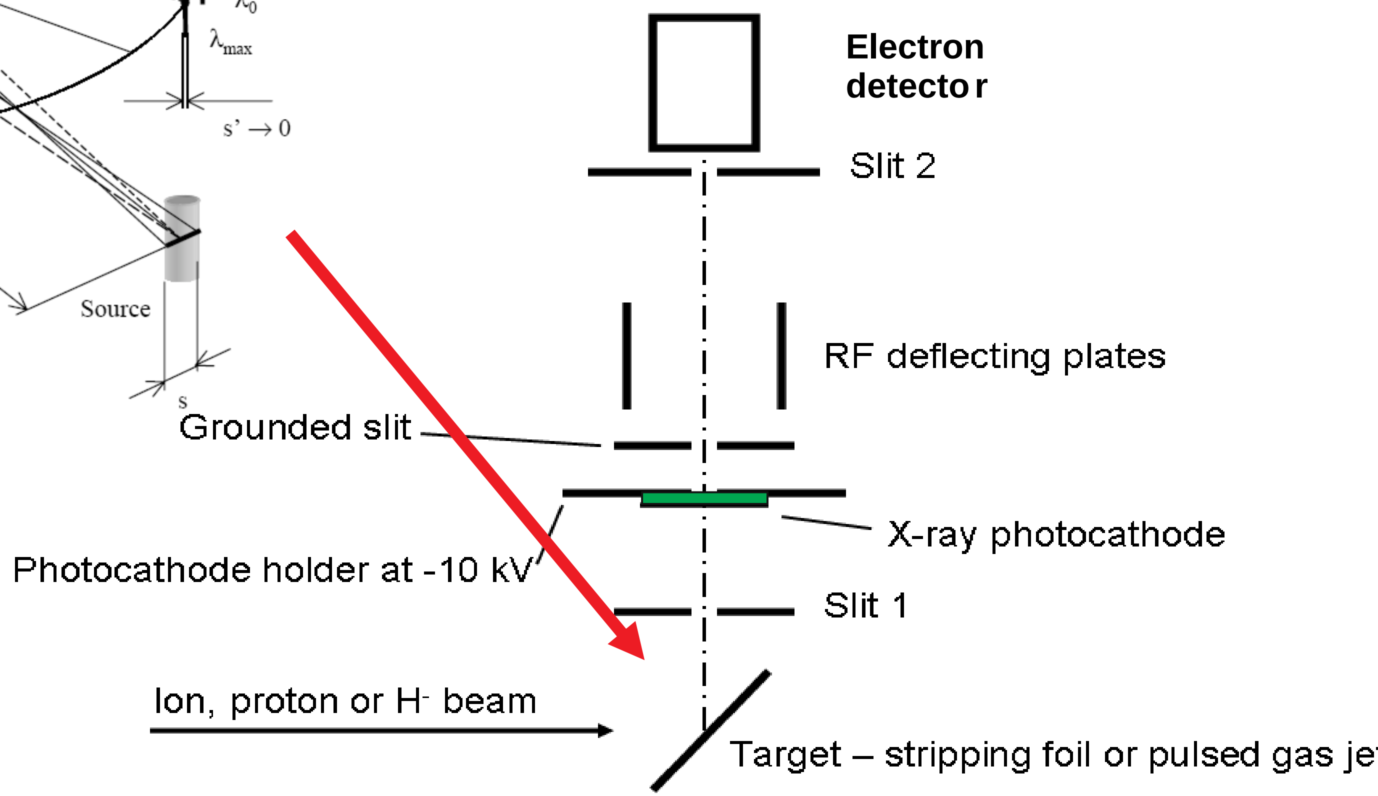
Bunch Length Detector based on photoelectrons

- Can be used for on-line longitudinal profile measurements in very high-power accelerators

Use spectrometer to select X-rays produced by filling of K-shell vacancies (8-10 keV)

- Improve time resolution to <5 psec

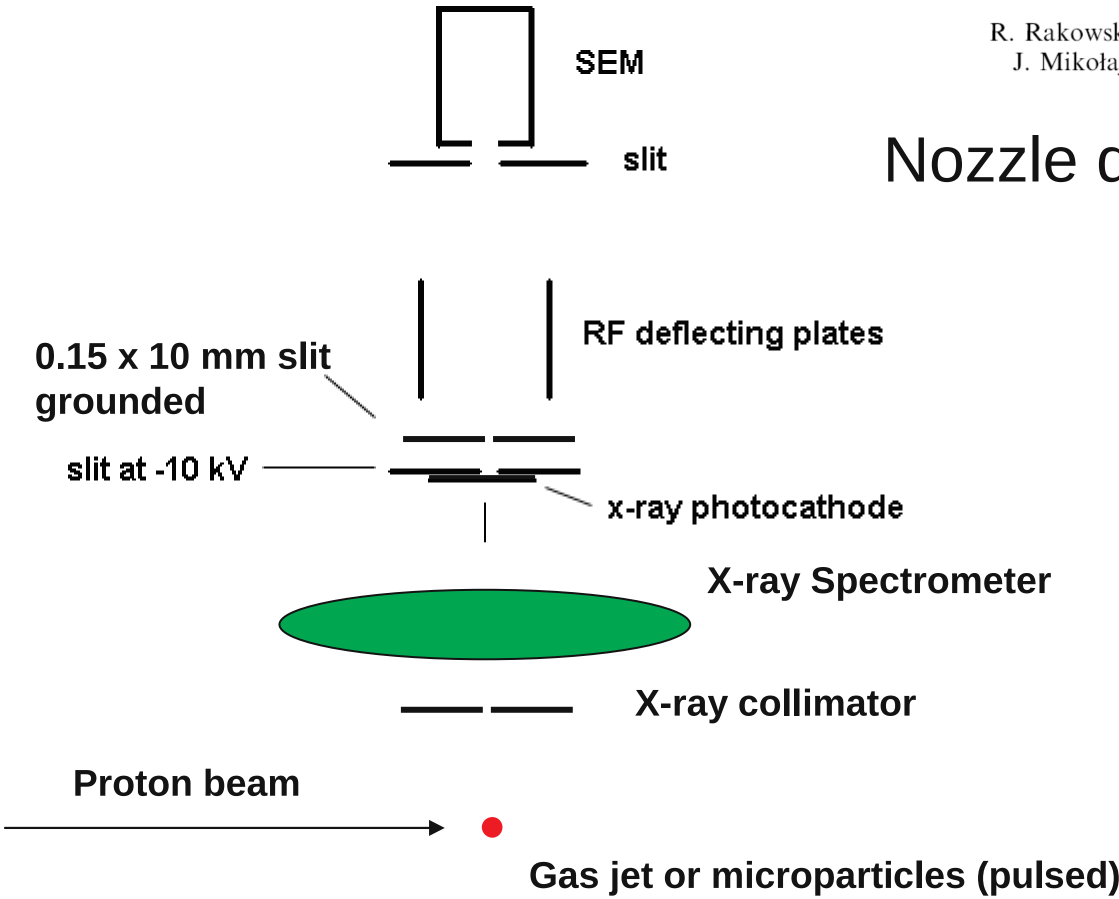




High-power proton accelerators

Pulsed X-ray radiography of a gas jet target for laser–matter interaction experiments with the use of a CCD detector

R. Rakowski[a], A. Bartnik[a], H. Fiedorowicz[a,*], R. Jarocki[a], J. Kostecki[a], J. Mikołajczyk[a], A. Szczurek[a], M. Szczurek[a], I.B. Földes[b], Zs. Tóth[c]



Nozzle design to produce a gas jet

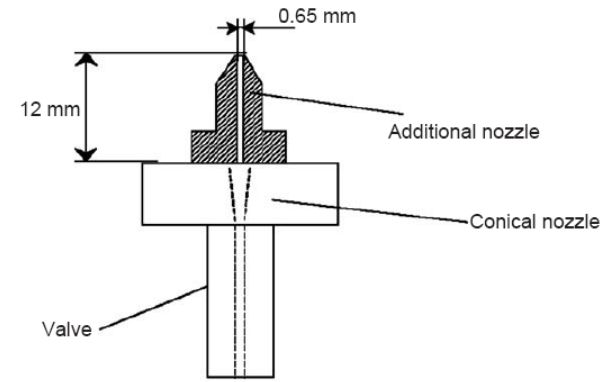
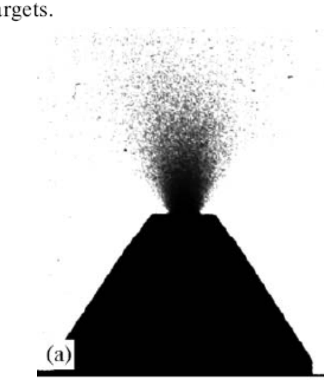


Fig. 2. Schematic diagram of the nozzle set-up to produce gas jet targets.



Summary

- We have developed and tested an X-ray based Bunch Length Detector (X-BLD) for application in ion accelerators
- The sensitivity of X-BLD is high enough to measure bunch length even for ion beams with quite low intensities such as 0.2 μA
- Temporal resolution of an X-BLD can be improved for high intensity ion beams by incorporation of an X-ray spectrometer into the device.
- An electron beam detection based on MCP-phosphor system has low dynamic range and requires improvement. Secondary Electron Multipliers are proven to be better option.
- High power proton and ion accelerators:
  - X-BLD can be applied for on-line monitoring of the bunch length. Requires either pulsed gas flow or dropping of micro-particles across the beam
  - No thermal issues with the target