High energy Coulomb scattered electrons detected in air used as the main beam overlap diagnostics for tuning the RHIC Electron Lenses

P. Thieberger[†], Z. Altinbas, C. Carlson, C. Chasman, M. Costanzo, C. Degen, K. A. Drees, W.Fischer, D. Gassner, X. Gu, K. Hamdi, J. Hock, A. Marusic, T. Miller, M. Minty, C. Montag, Y. Luo and A.I. Pikin, Brookhaven National Laboratory, Upton, NY 11973, USA and S.M. White, European Synchrotron Radiation Facility, BP 220, 38043 Grenoble Cedex, France.

Most of this material appears in an article by the same authors entitled "High energy Coulomb-scattered electrons for relativistic particle beam diagnostics",
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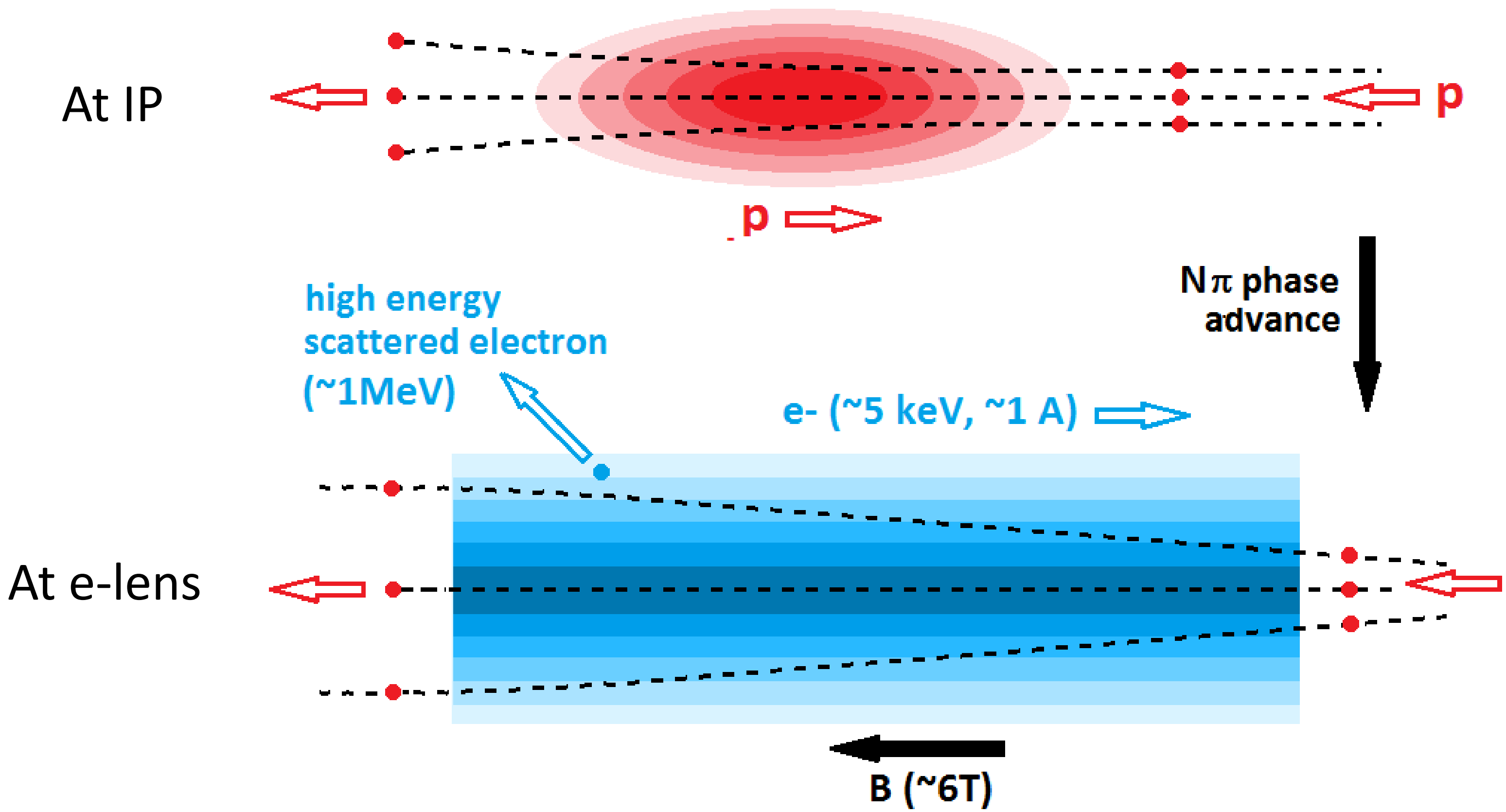
OUTLINE

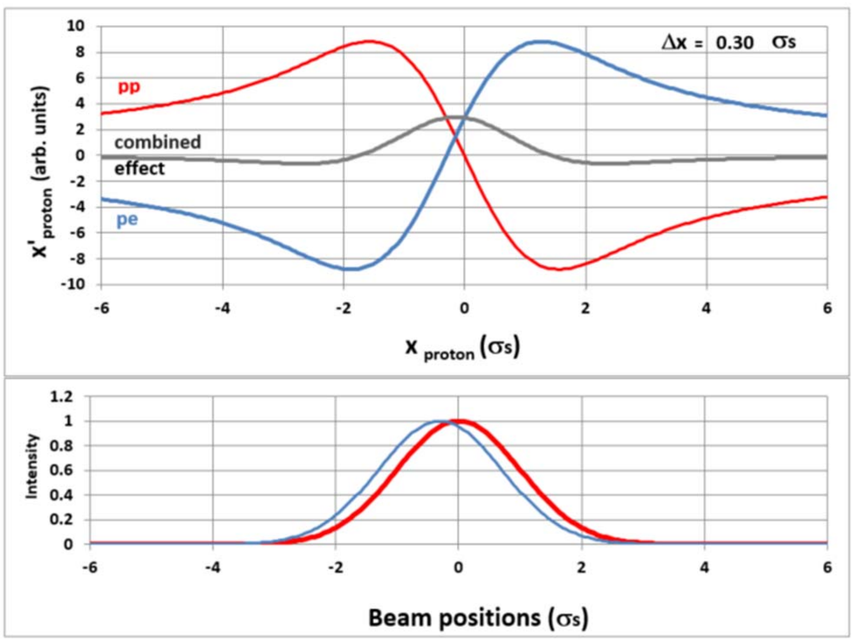
- The beam-beam effect limiting RHIC pp luminosity is partially compensated by using two electron lenses.
- Alignment of the overlapping electron and proton beams in these lenses is critical.
- A new beam-overlap diagnostic tool, the electron backscattering detector (eBSD), is described in detail.
- Results are described for the commissioning of these instruments and for their successful use during the 2015 pp RHIC run.
- Other possible non-invasive, real-time diagnostic applications are briefly mentioned.

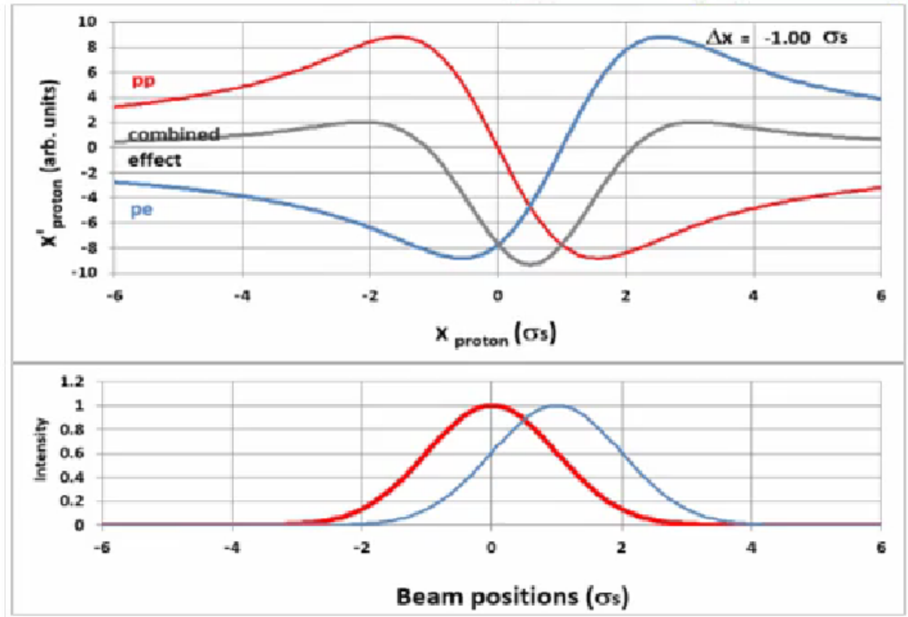
One electron lens for each proton beam cancels the beam-beam radial kicks.
Coulomb – scattered electrons are used for beam overlap optimization.



Electron lens misalignment effects

- Only a slight misalignment can be tolerated for effective compensation of the beam-beam effect.
- A significantly misaligned lens is worse than no lens at all.
- The maximum tolerable misalignment is of the order of 0.3 σ :

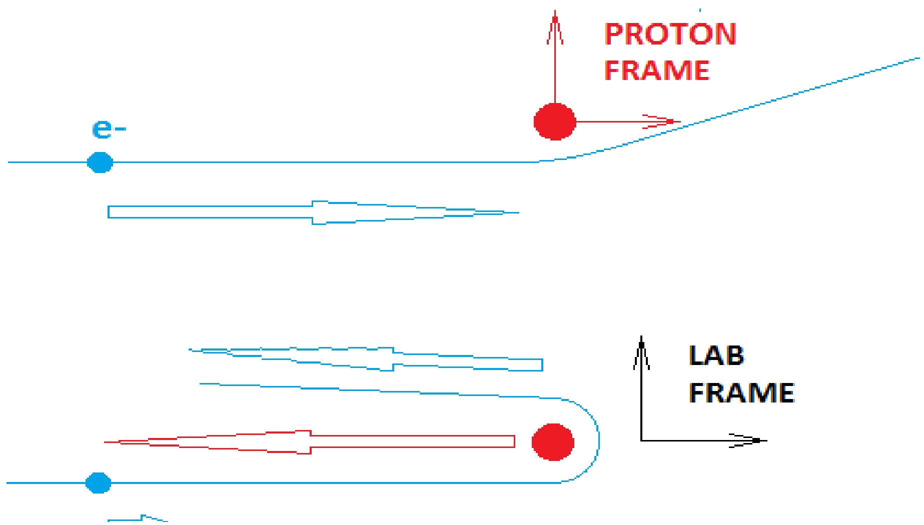




- Using BPMs for achieving and maintaining alignment is very challenging.
- The DC electron beam needs to be chopped, which may affect its stability.
- Very different pulse shapes lead to unavoidable electronic offsets.
- **Instead of determining individual beam position, an overlap or luminosity monitor is required.**

Approach for estimating scattered electron energies an intensities

A coordinate transformation to the proton frame (top) lets us use standard Rutherford-scattering equations. Transforming the results back to the lab frame (bottom) yields the results shown on the next slide.

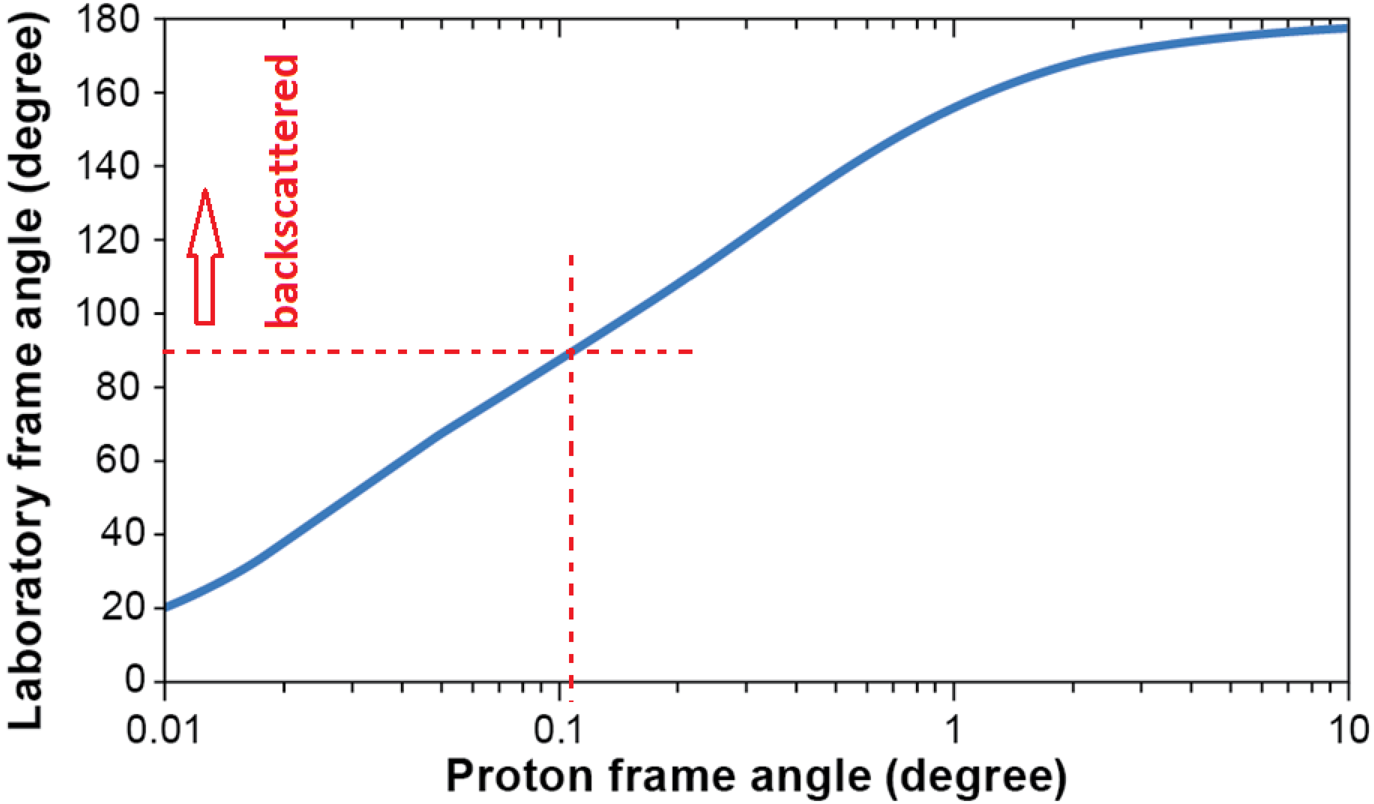


$\boldsymbol{p}$ = momentum $\boldsymbol{E}$ = energy $\boldsymbol{\theta}$ = angle of the electron in the ion frame

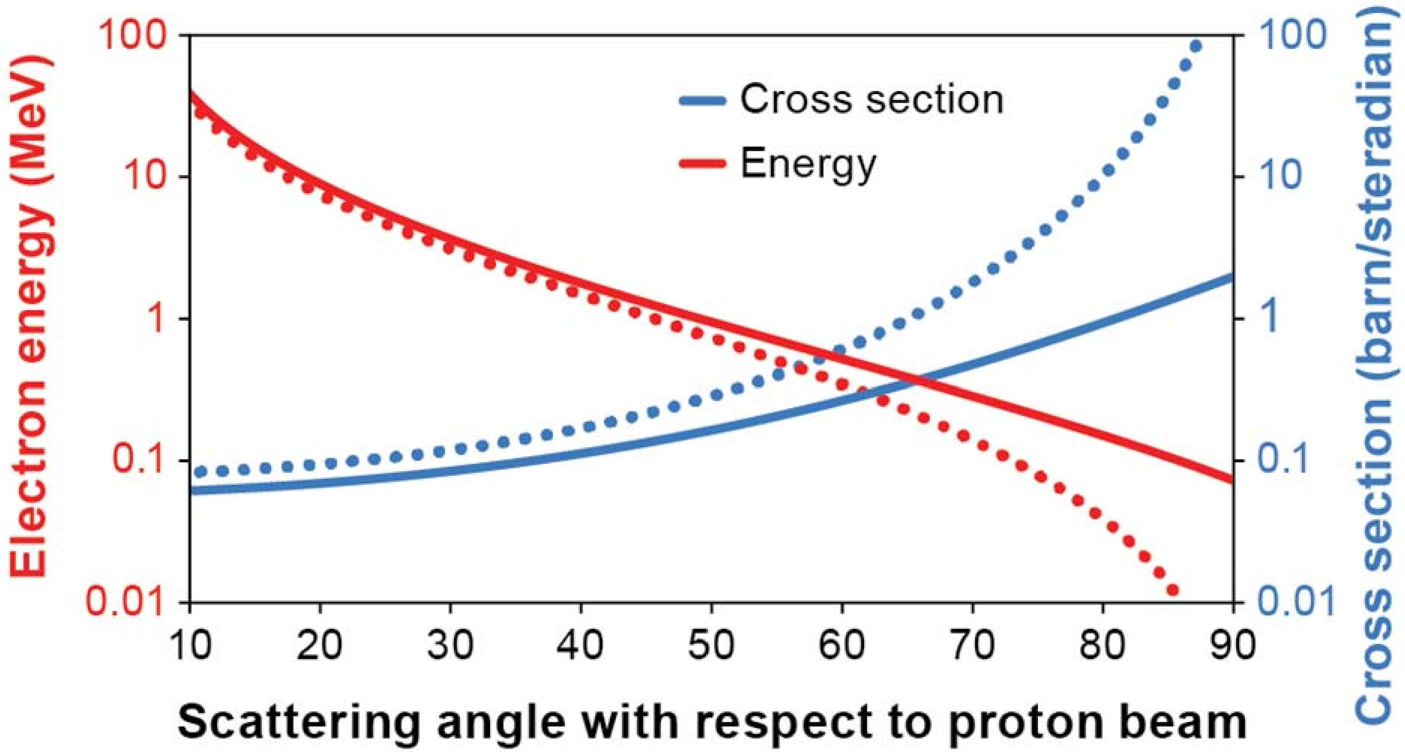
$$\frac{d\sigma}{d\Omega} = \frac{Z^2}{4}\left(\frac{e^2}{E}\right)^2 \frac{1}{sin^4(\theta/2)} \times \left[1 - \left(\frac{pc}{E}\right)^2 sin^2\frac{\theta}{2}\right] \times \left[1 + \frac{2E\, sin^2(\theta/2)}{M_p c^2}\right]^{-1} \times \left[1 - \frac{q^2 \tan^2(\theta/2)}{2M_p^2}\right]$$

Rutherford **Quantum corr.** **Recoil corr.** **Magnetic moment corr.**

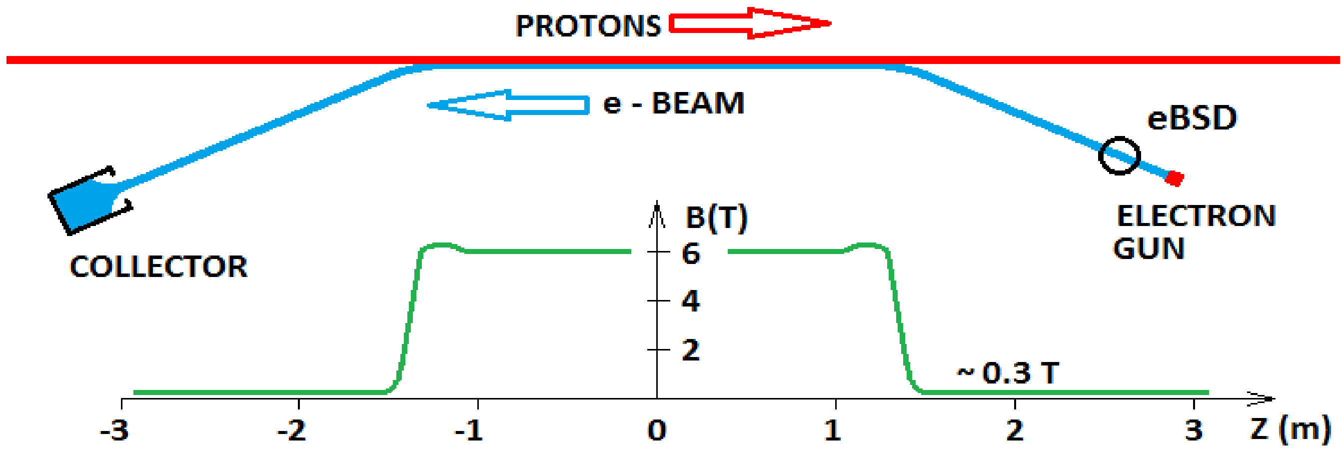
Scattering angles in the lab frame of 5 keV electrons scattered by 250GeV protons as function of the corresponding angles in the proton frame. In the proton frame, the electron beam energy is 157 MeV.



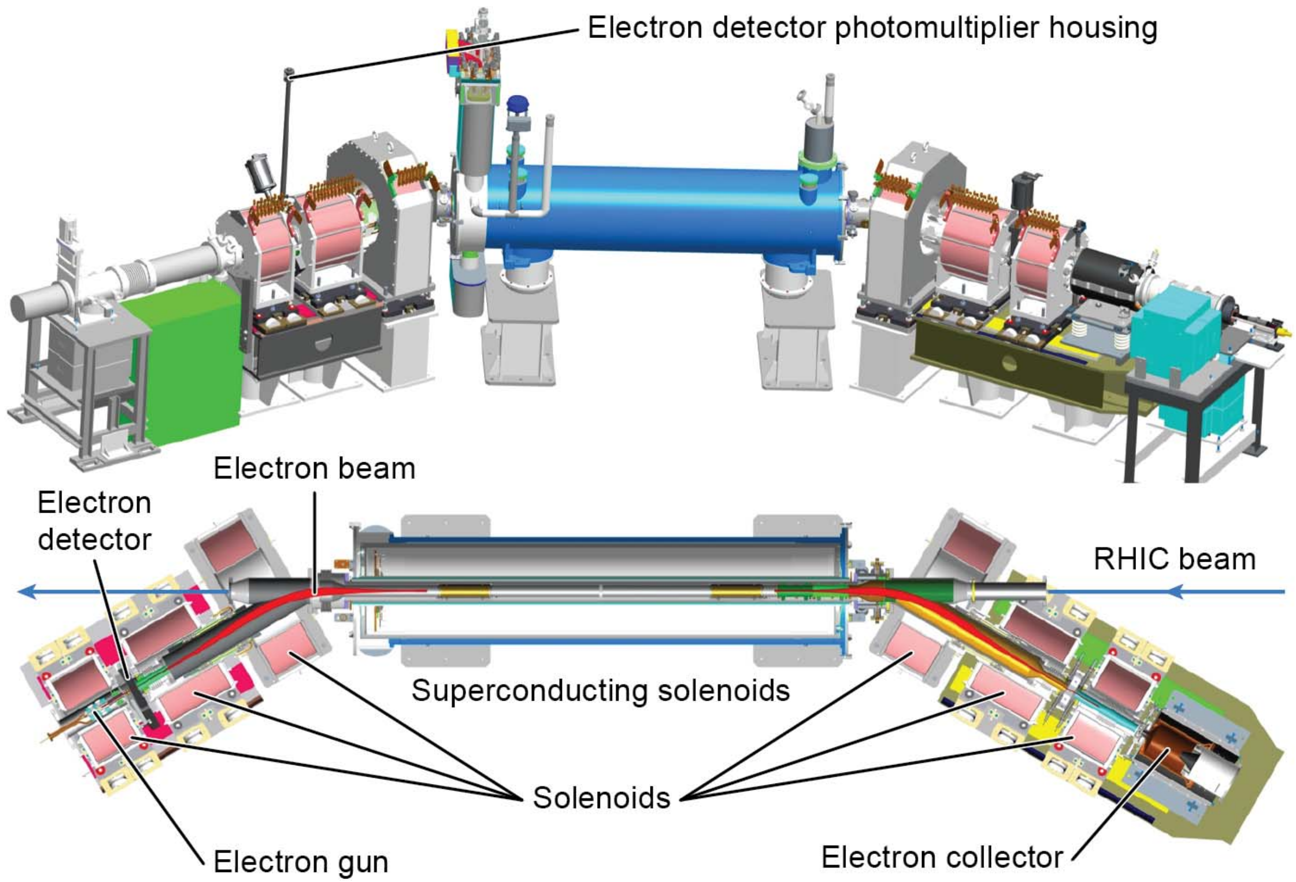
Energies and scattering cross-sections of 5 keV electrons and 10 eV electrons (dotted lines) backscattered by 250 GeV protons as function of the scattering angle.



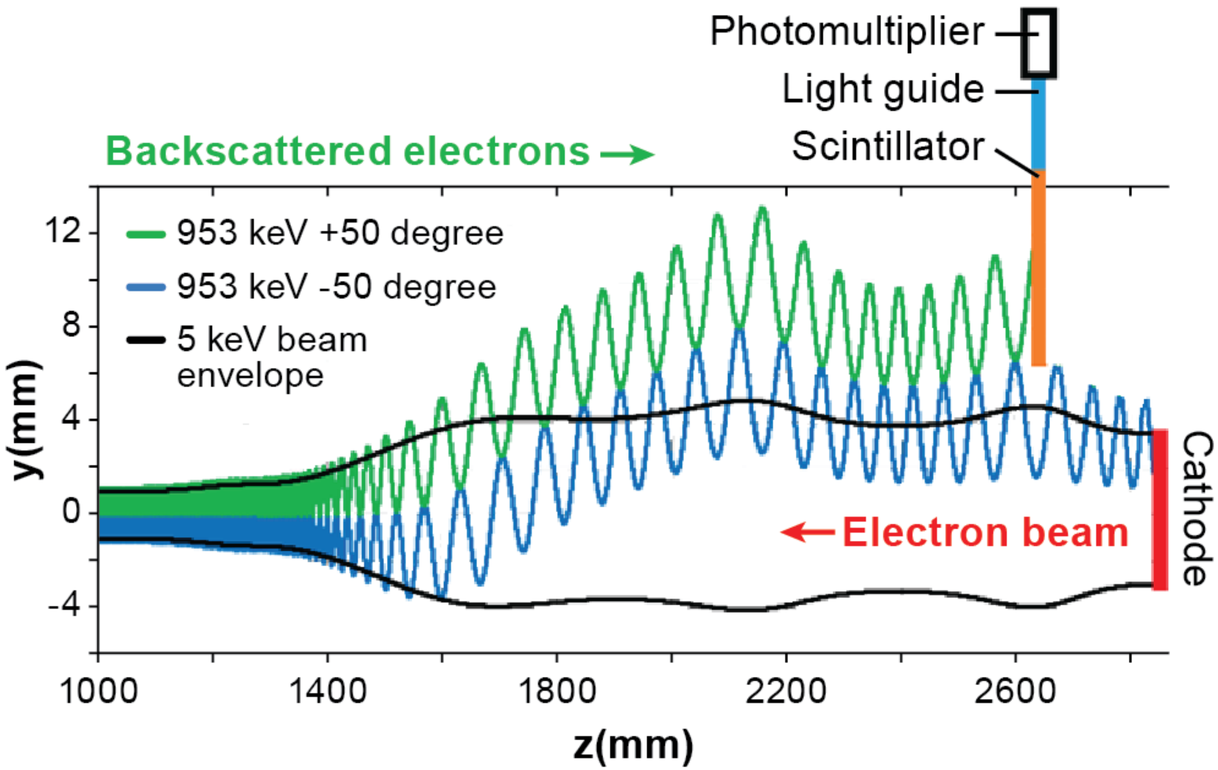
Electron beam trajectory and values of the guiding magnetic field in one of the two e-lenses



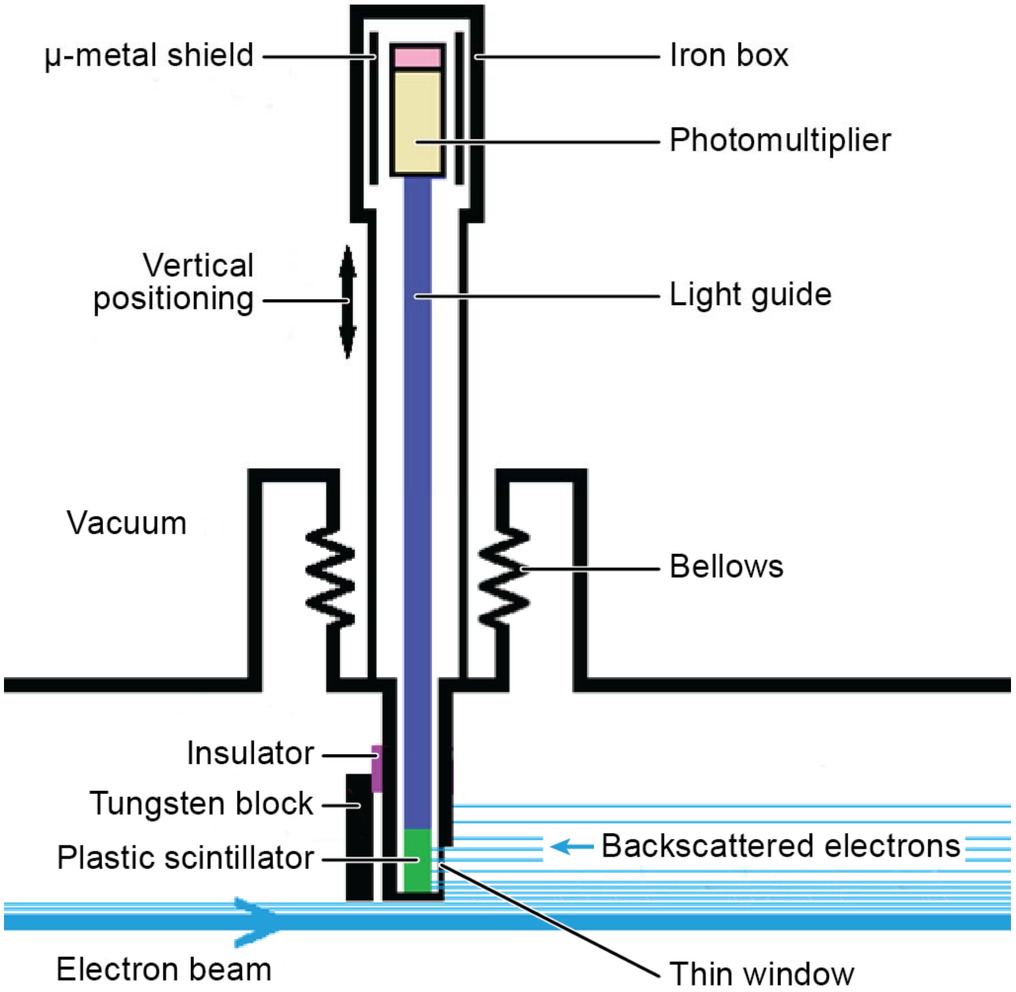
Perspective and plan view of one of the RHIC electron lenses.



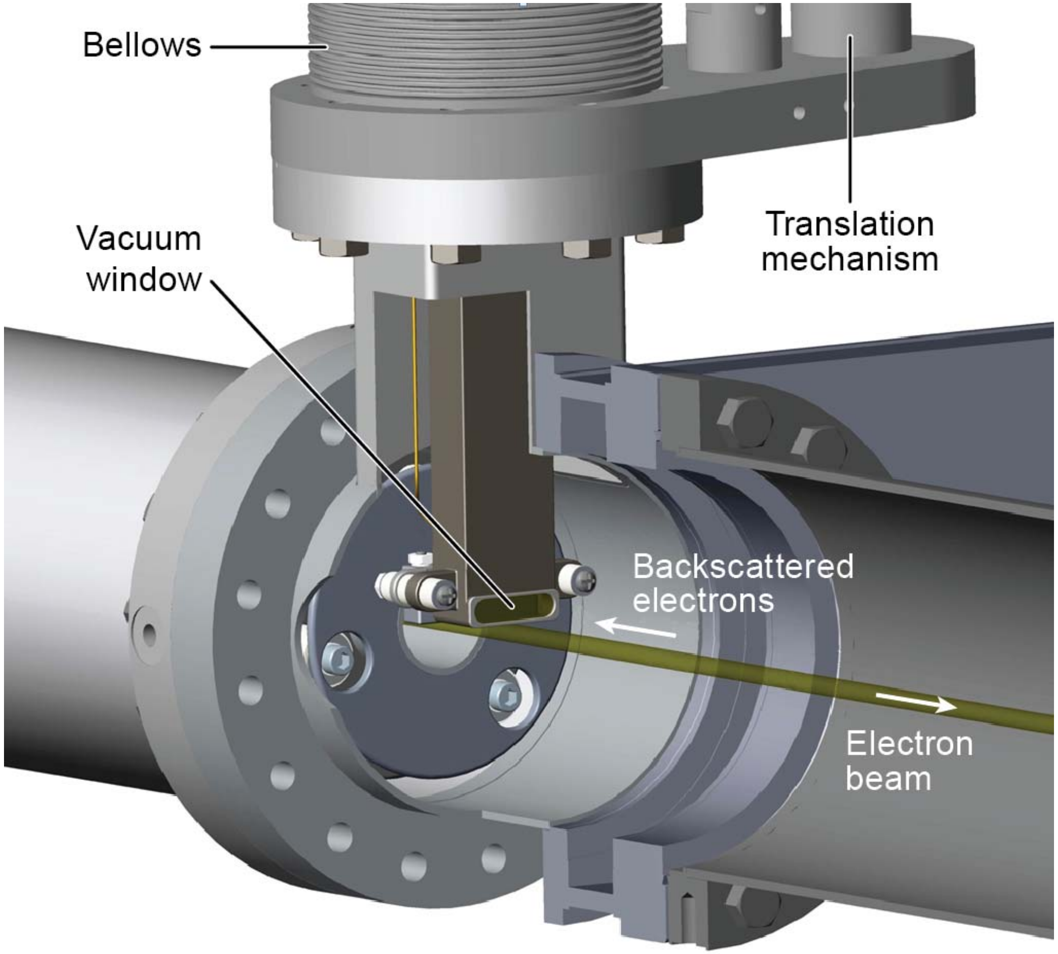
Simulated trajectories of two scattered electrons generated inside the 6 T solenoid



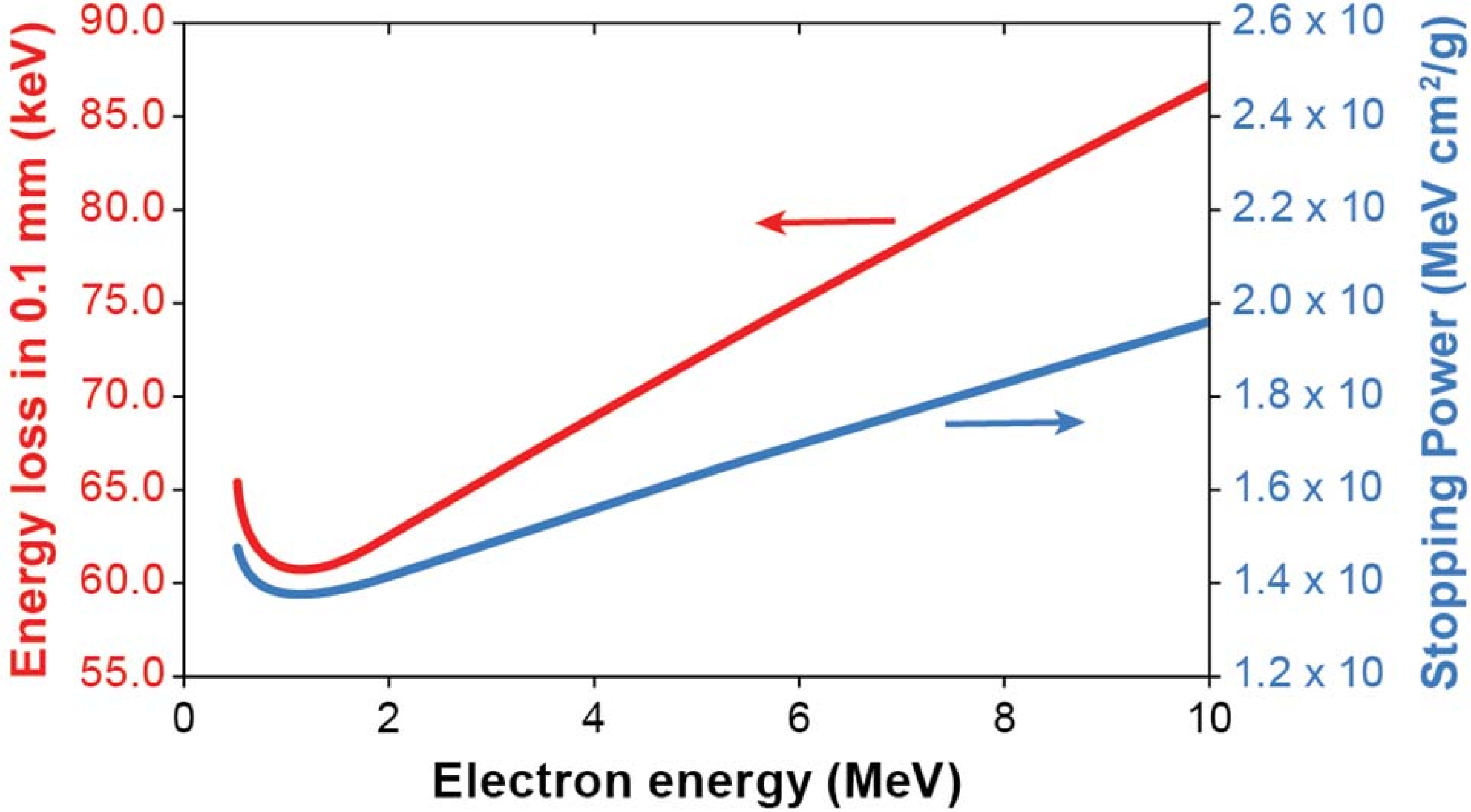
Schematic of the electron backscattering scintillation detector (eBSD) and its housing.



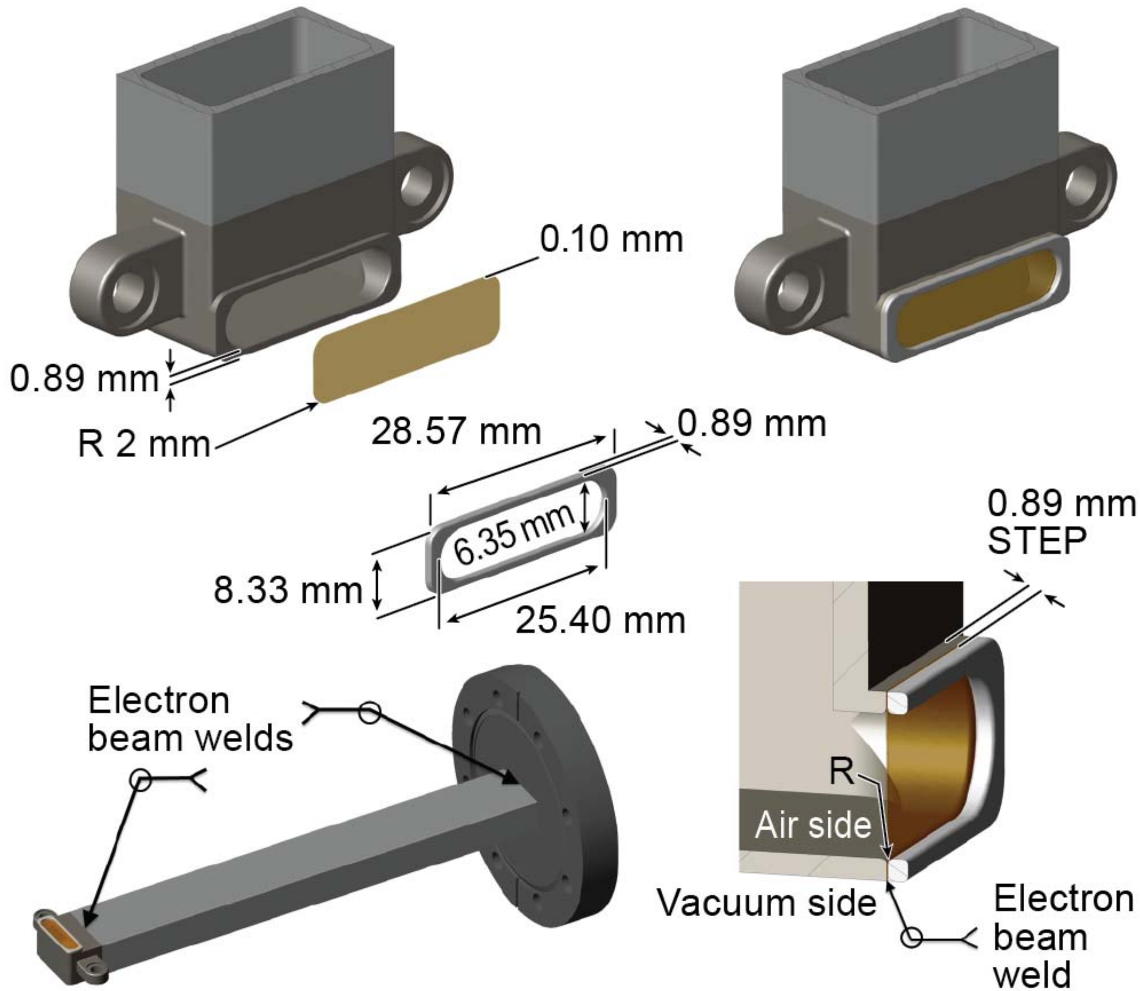
Cutaway drawing of the detector housing and the vertical translation mechanism



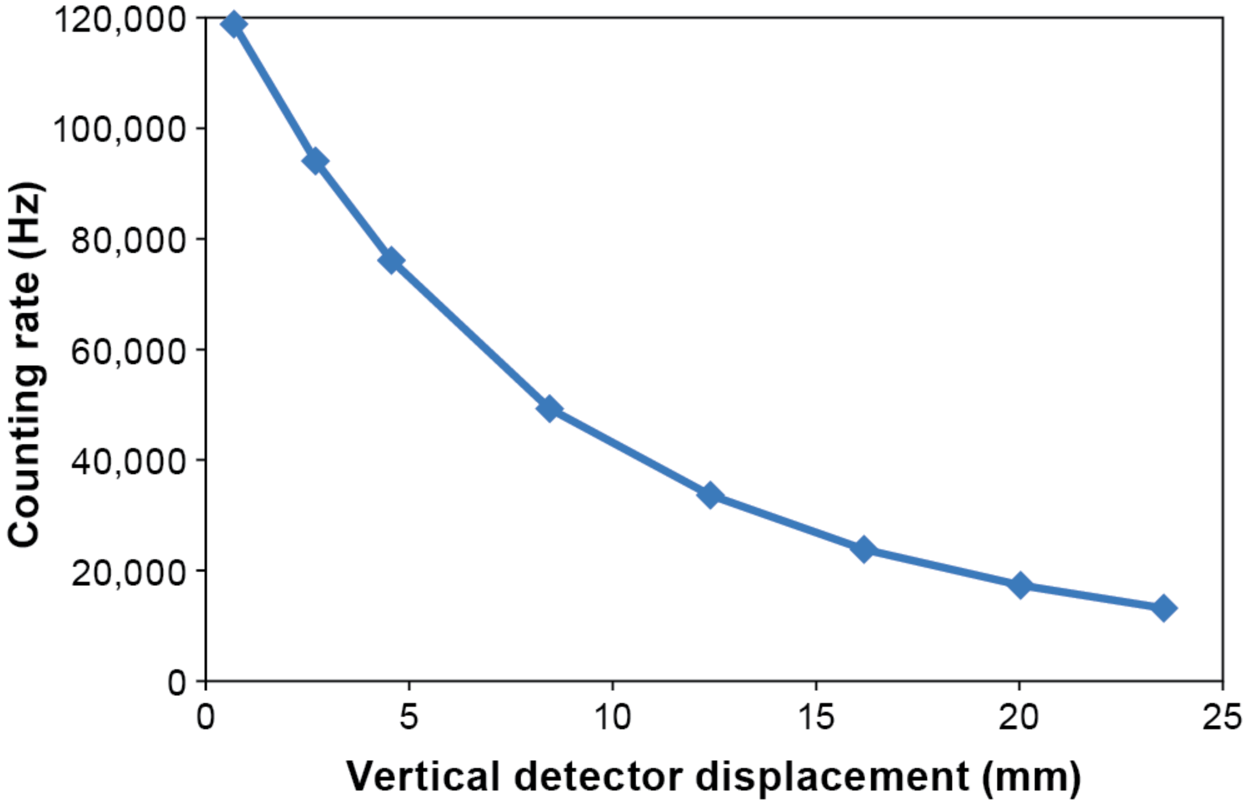
Stopping power (blue) and energy loss in the 100 μm thick titanium window (red) as function of electron energy.



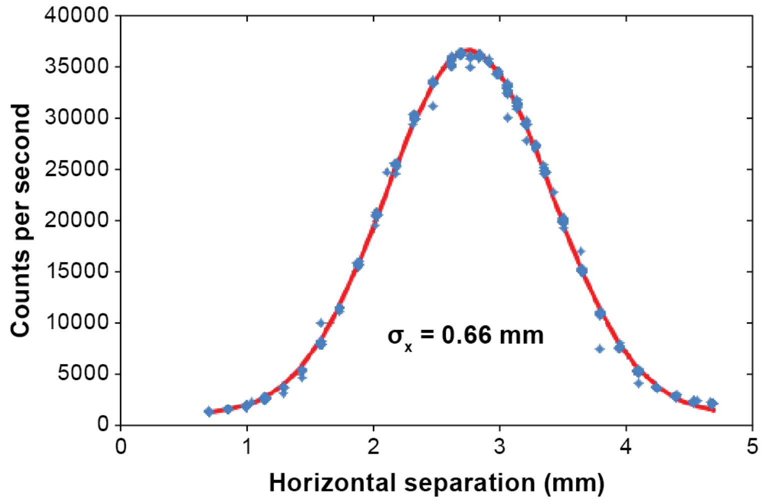
Mechanical details of the detector housing and of the 100 μm thick titanium vacuum window

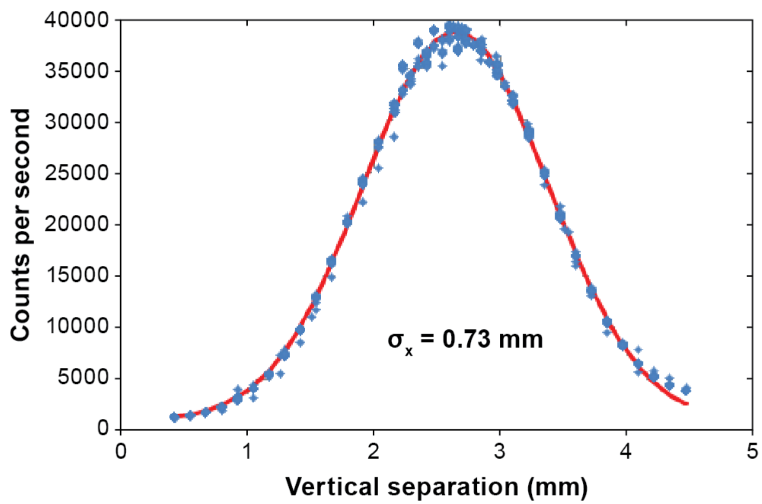


Counting rate as function of vertical displacement of the eBSD detector obtained with a ^{3}He beam consisting of 93 bunches with 4.7 E10 ions per bunch and a 6 keV, 88 mA electron beam.

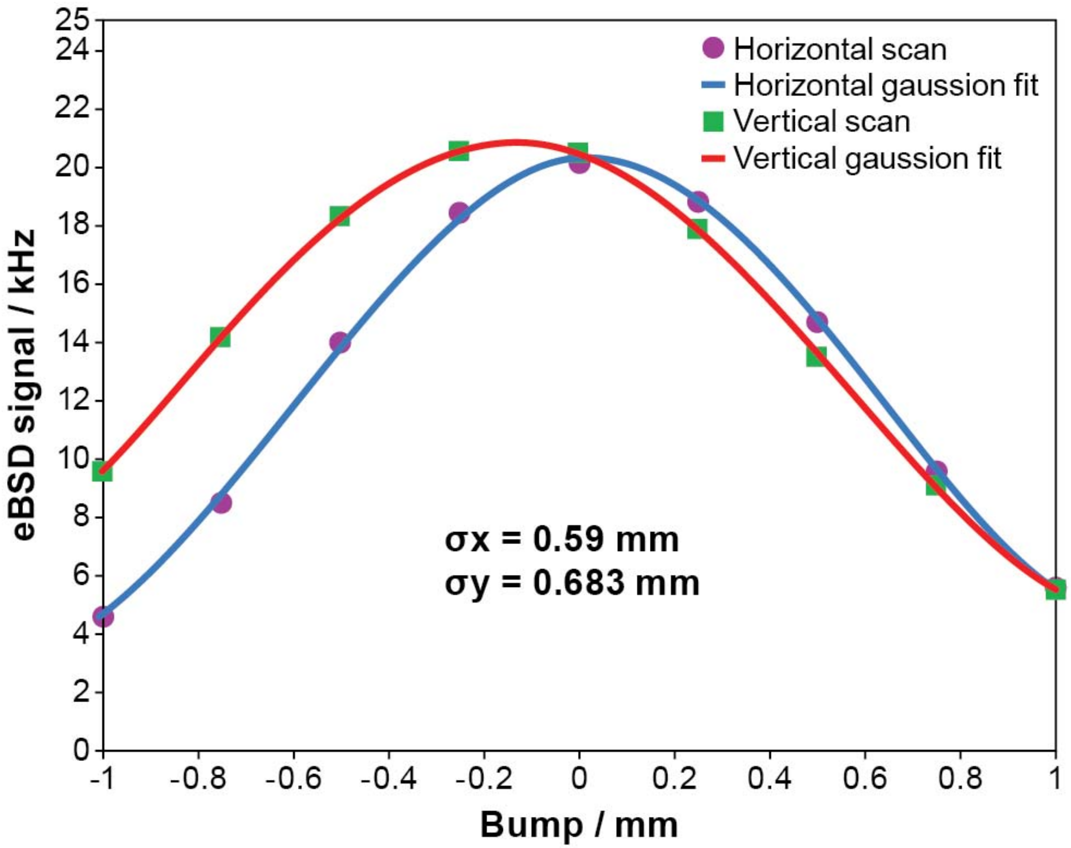


Horizontal and vertical beam separation scans obtained by steering the 5 keV electron beam with respect to the 100 GeV/nucleon gold beam.

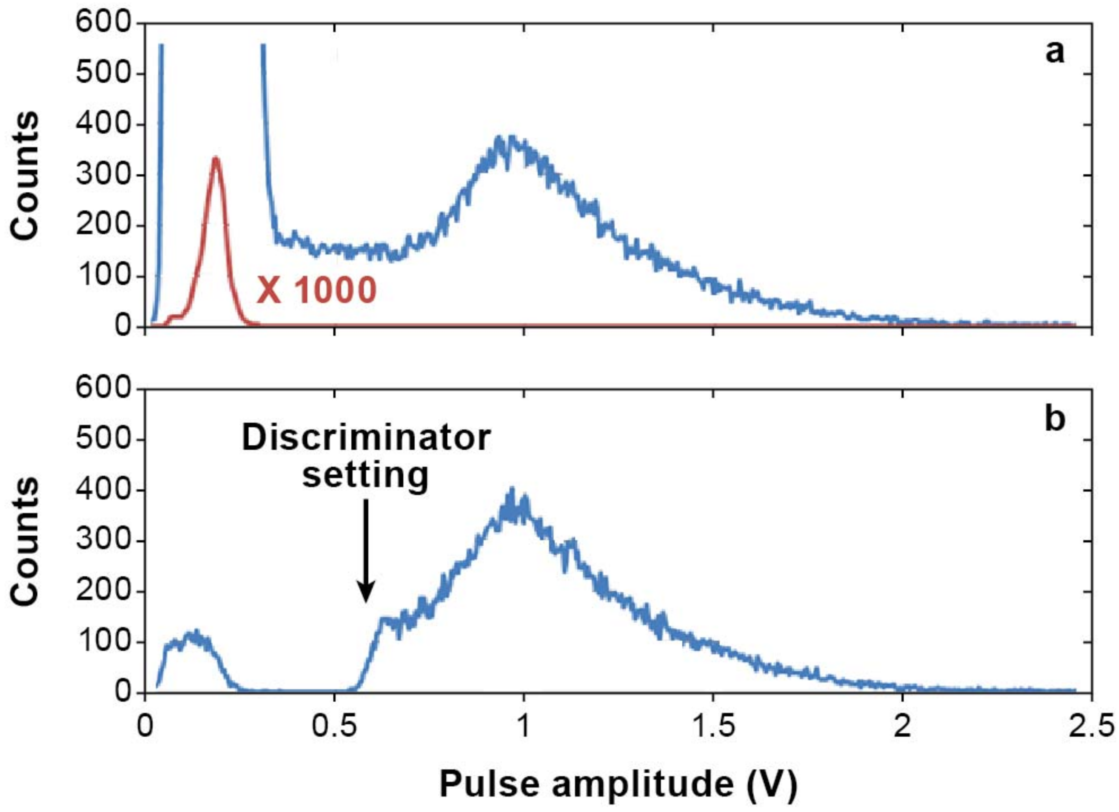




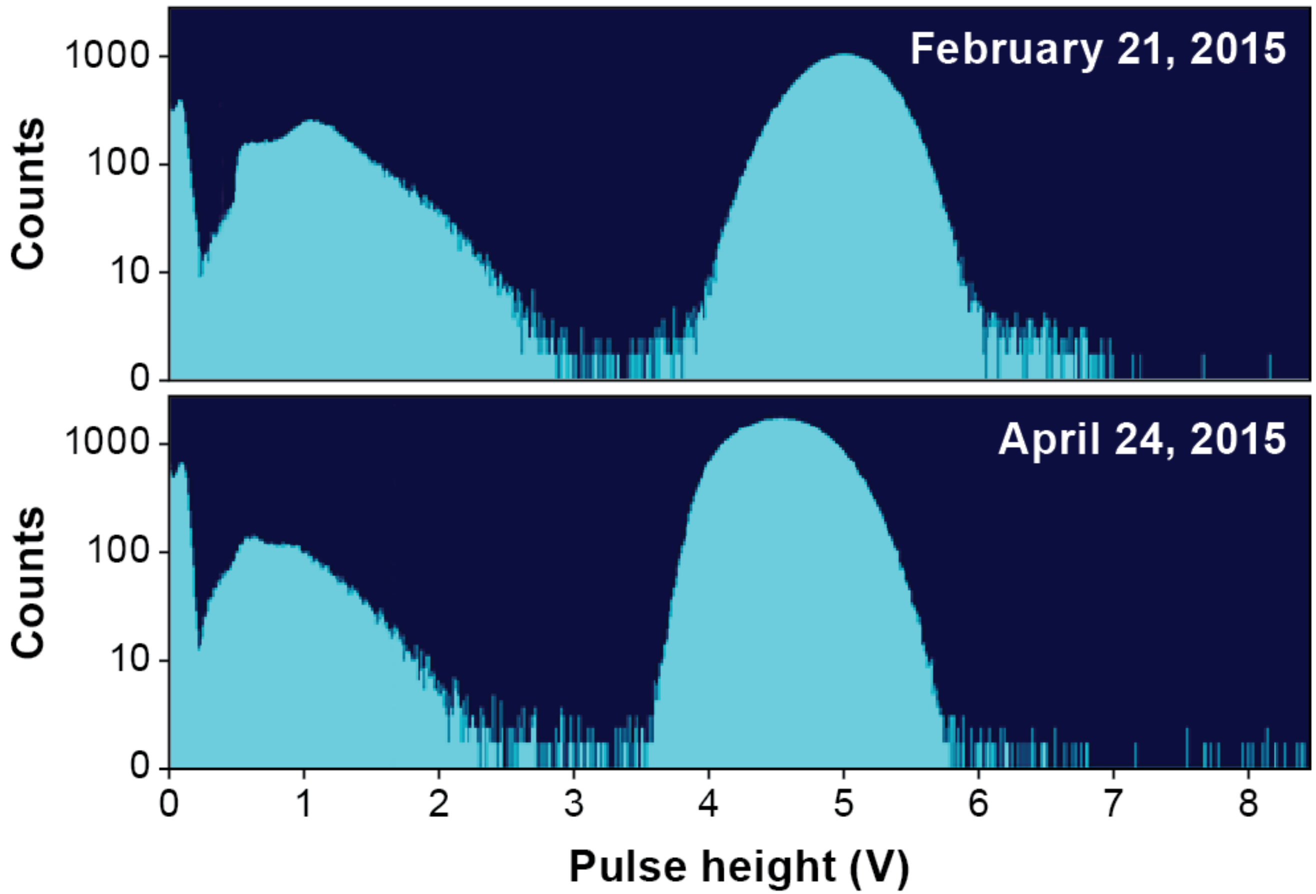
Manual beam separation scans obtained by steering the 100 GeV/u ^{3}He beam using a closed orbit bump.



Pulse height spectrum from the scintillation detector used in one of the RHIC electron lenses.



eBSD pulse-height spectra including the signal of a high precision light pulser (right peak) obtained at the beginning and the end of the 2 month long proton run.

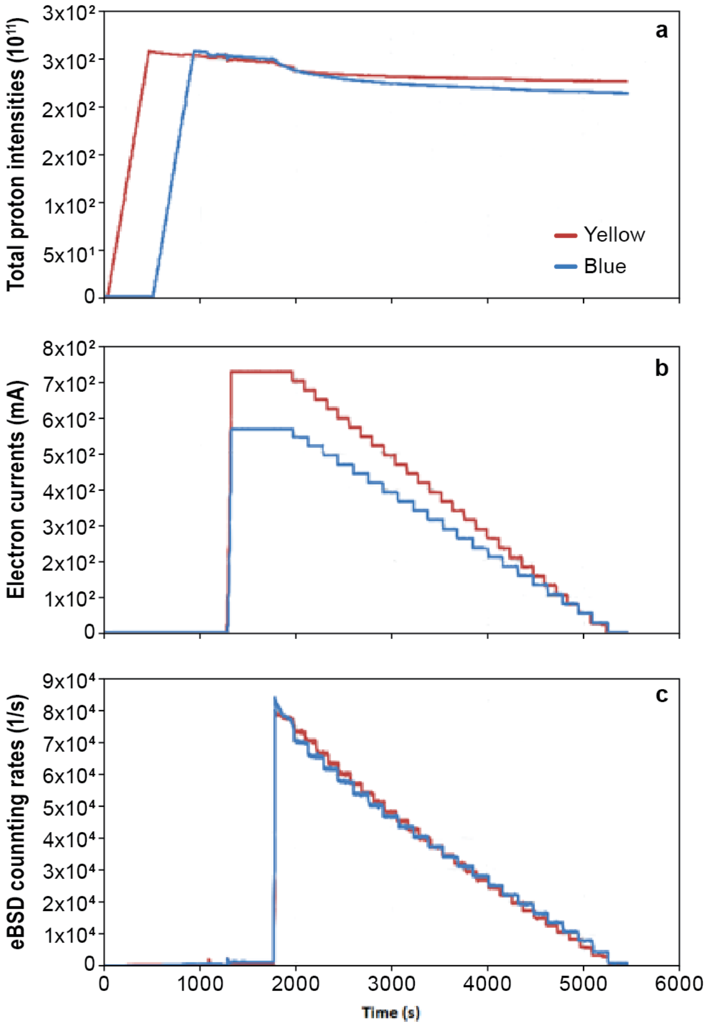


PERFORMANCE DURING ONE STORE

Total proton intensities

Electron beam currents

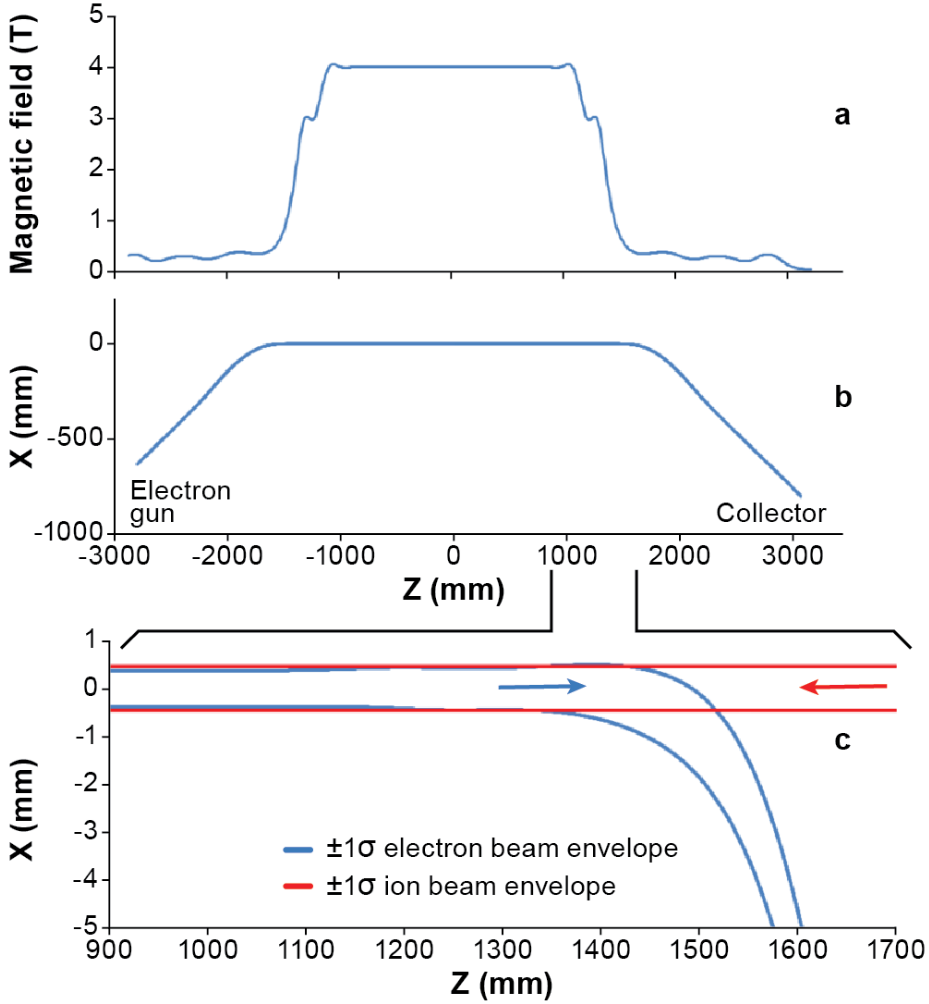
eBSD counting rates



Source of one of the systematic errors

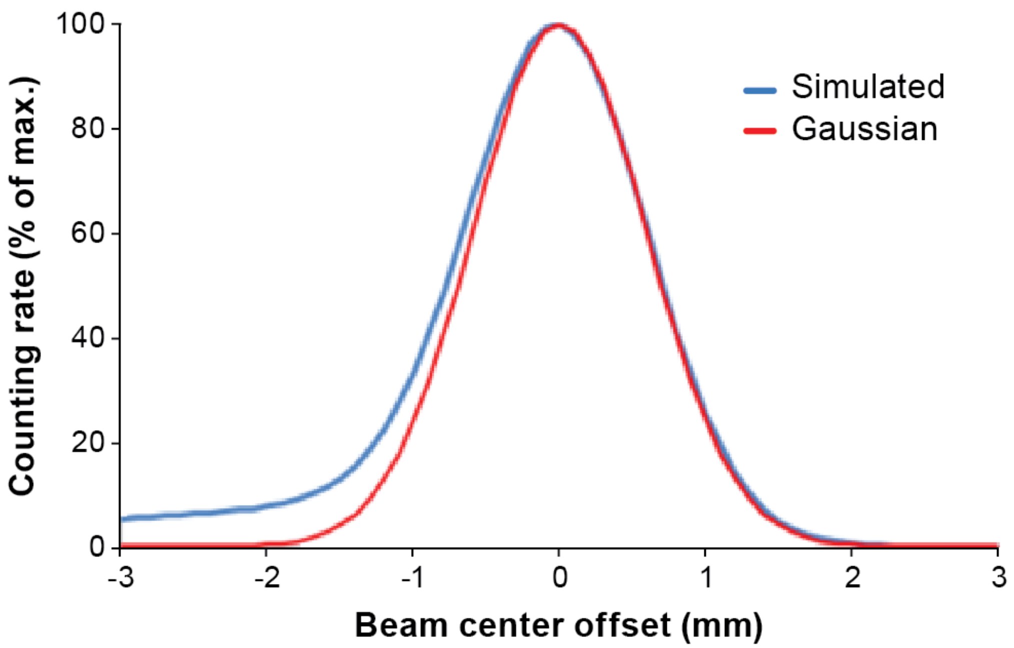
Magnetic field profile (a) and beam trajectories and envelopes (b and c) used for the evaluation of one of the systematic error sources.

Over a small fraction of beam the overlap regions, the electron beam isn't centered with respect to the proton beam.



Systematic error analysis

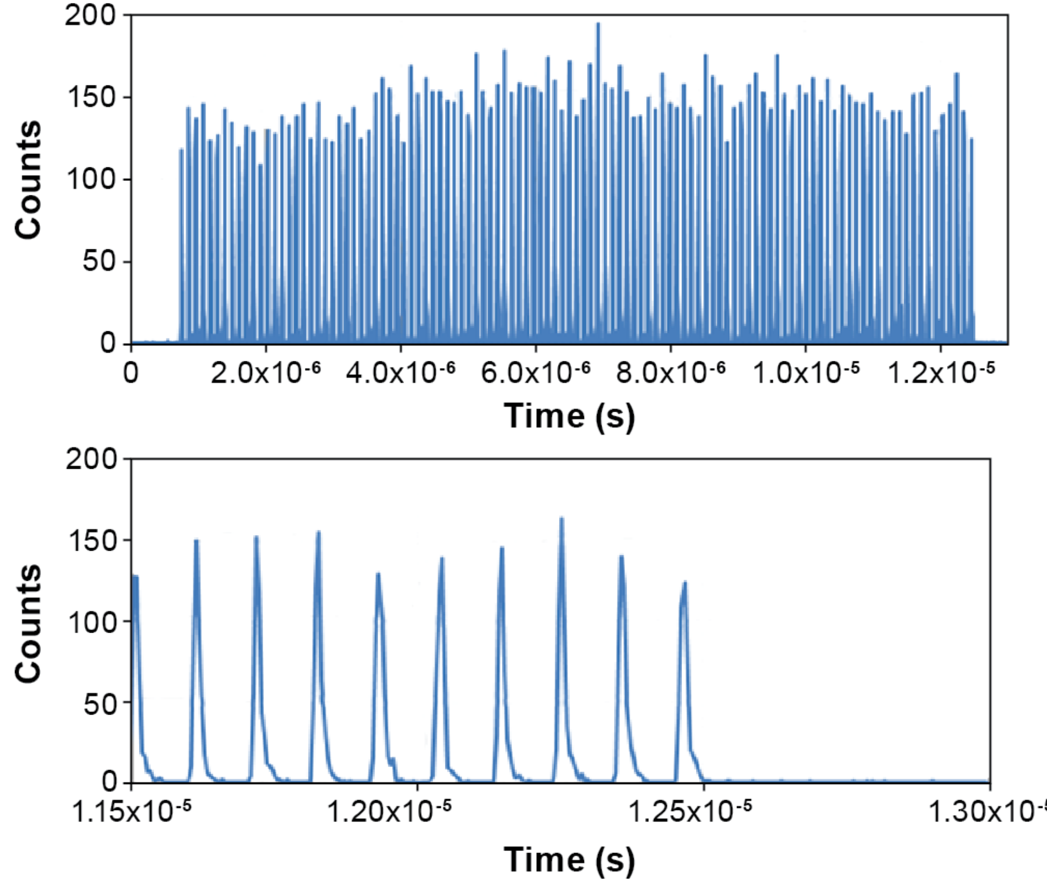
Simulated peak asymmetry (blue) calculated for the parameters shown in the previous slide. The calculated peak position error was 18 μm which was negligible in this case but could be applied as a correction if necessary.



Residual gas effects

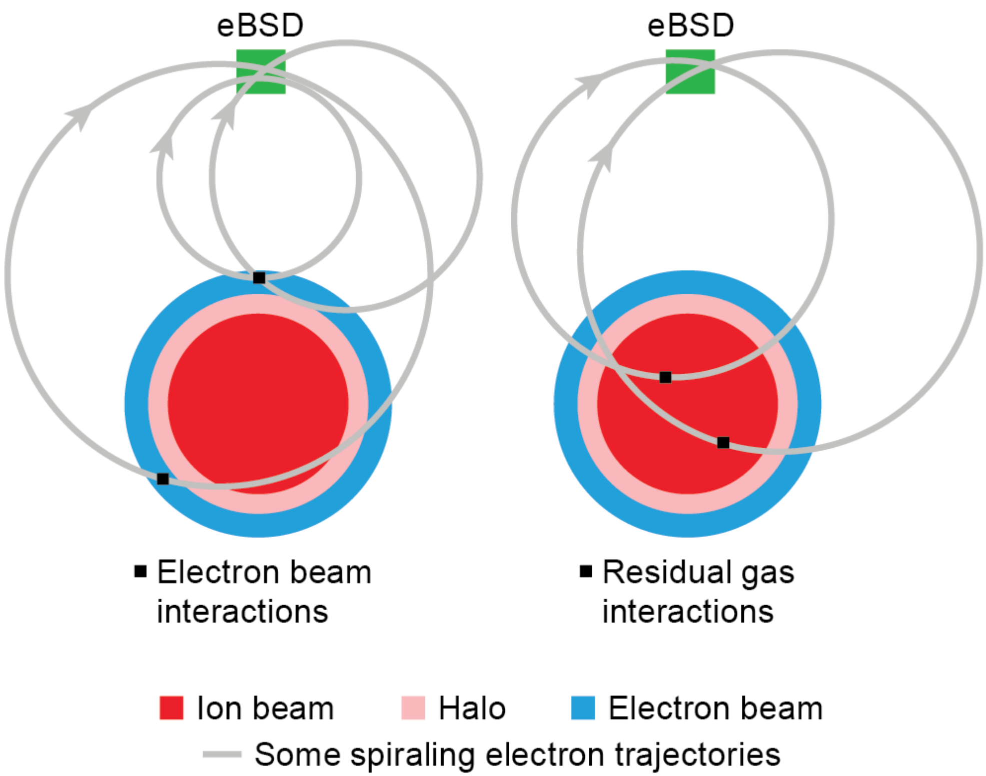
Time-of-flight spectra of electrons generated by the interaction of the 100 GeV/u proton beam with the residual gas.

The intensity pattern reflects the proton bunch intensity variations.



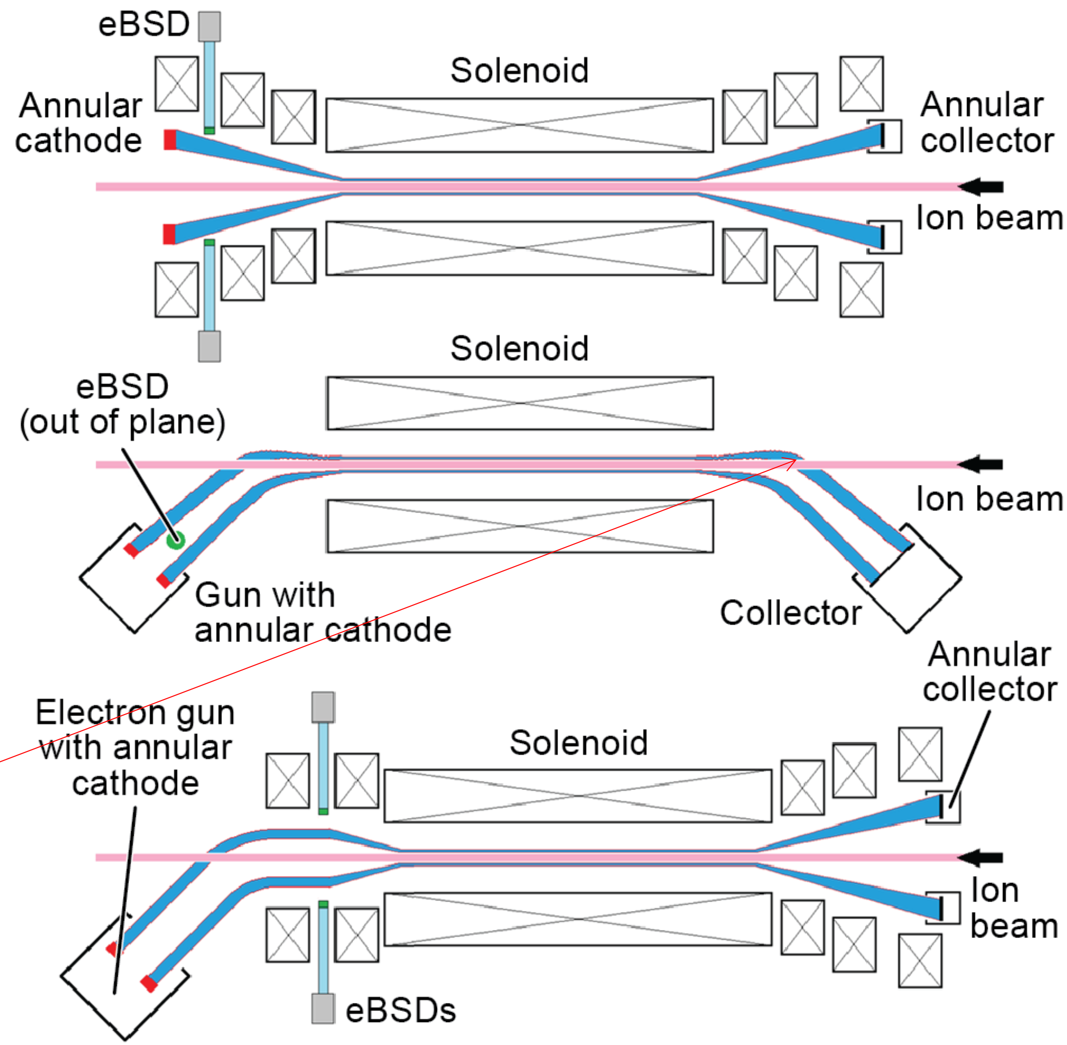
Potential use of eBSDs for beam halos monitoring.

Electrons from a hollow electron beam (blue) are scattered by halo ions (pink) , spiral along field lines and are counted in eBSDs (left). Extremely good vacuum is required to minimize counts originating from ion-gas interactions (right).



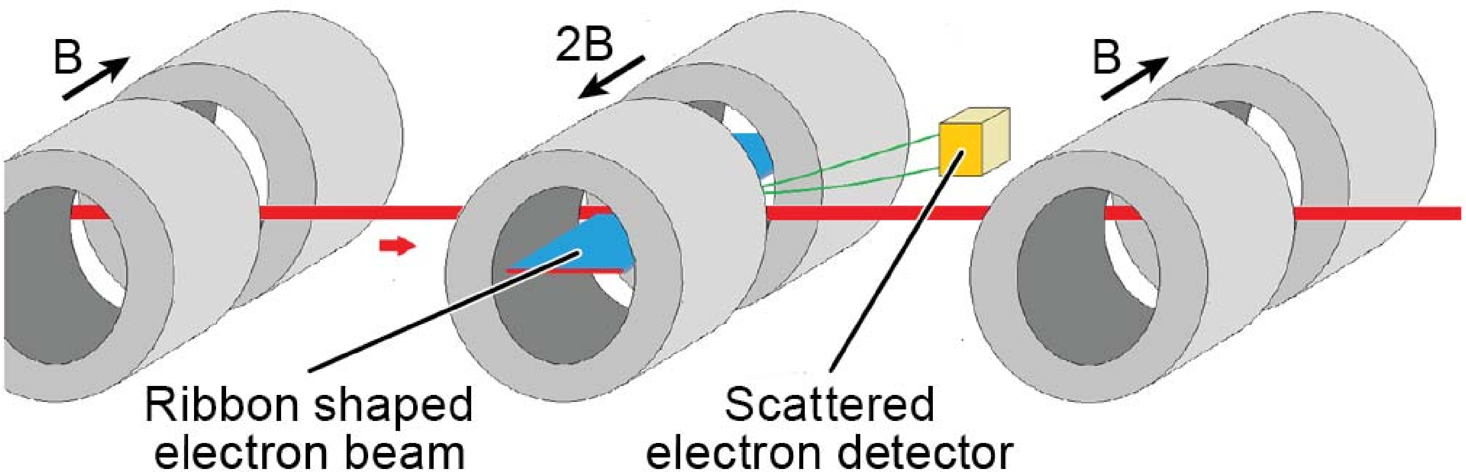
Three possible configurations for using eBSDs for beam halo monitoring.

The bottom option eliminates the need for an annular cathode surrounding the ion beam (top) and avoids background counts from an electron-ion beam crossing (center).

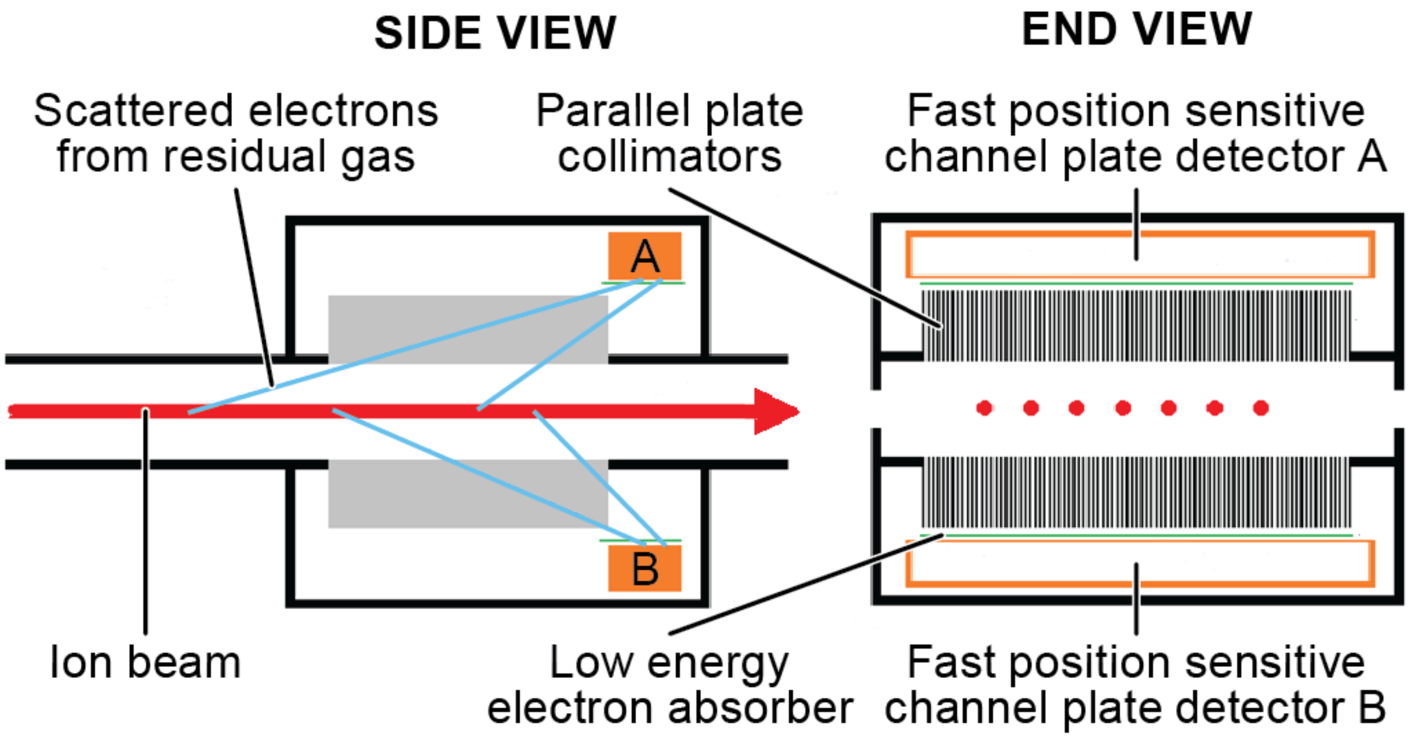


Concept for a Coulomb scattering "electron wire" beam profile monitor.

A magnetized ribbon-shaped electron beam intersects the ion beam. The scattered electron counting rate measures the degree of beam overlap. The ion or the electron beam is scanned to obtain a profile.



Concept of a multiple beam BPM based on scattered electrons from the residual gas.



CONCLUSIONS

- High energy electrons produced in small impact parameter Coulomb interactions with relativistic ions are being successfully used for beam alignment in the RHIC electron lenses.
- Based on this experience, other such non-invasive, real time beam diagnostic tools may be developed in the future.