Ion Induced Beam disruption Mechanism

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DARHT / AIRIX projects:

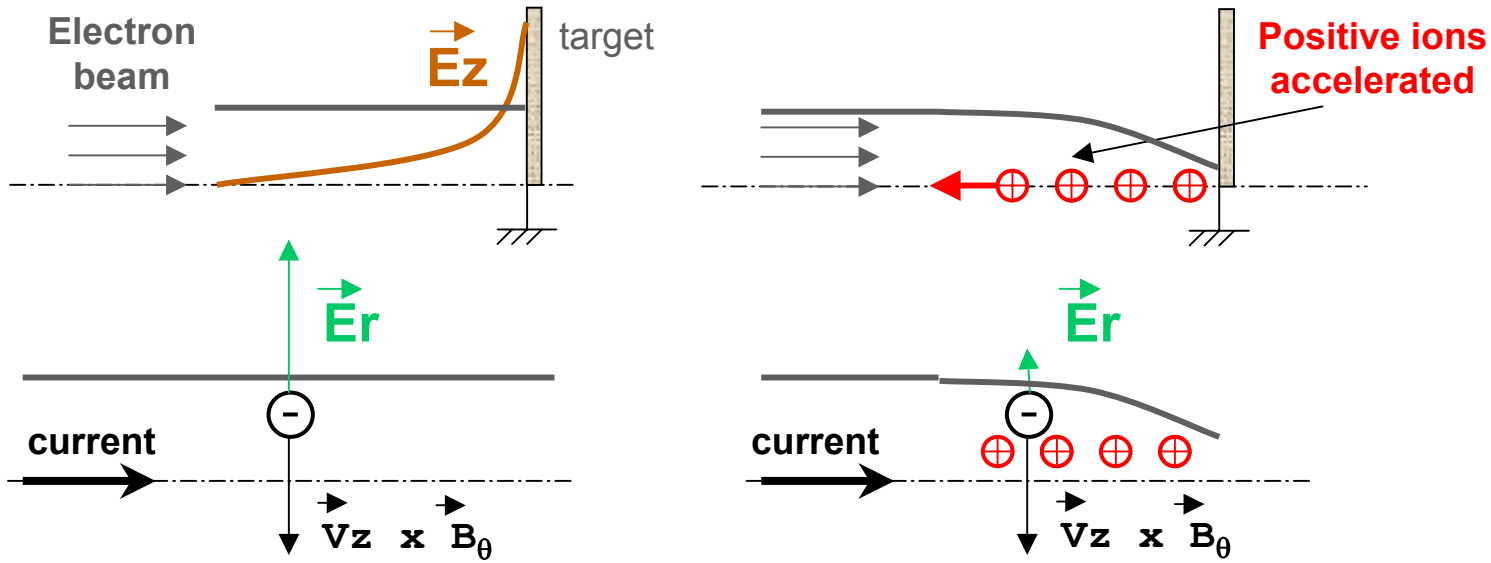
Linear Induction Accelerator for Flash X-rays Radiography

single pulse electron beam
2-4 kA, 20 MeV, 60 ns
→ High Z material target → **Flash X-rays source**
500 rad@1m, 2 mm

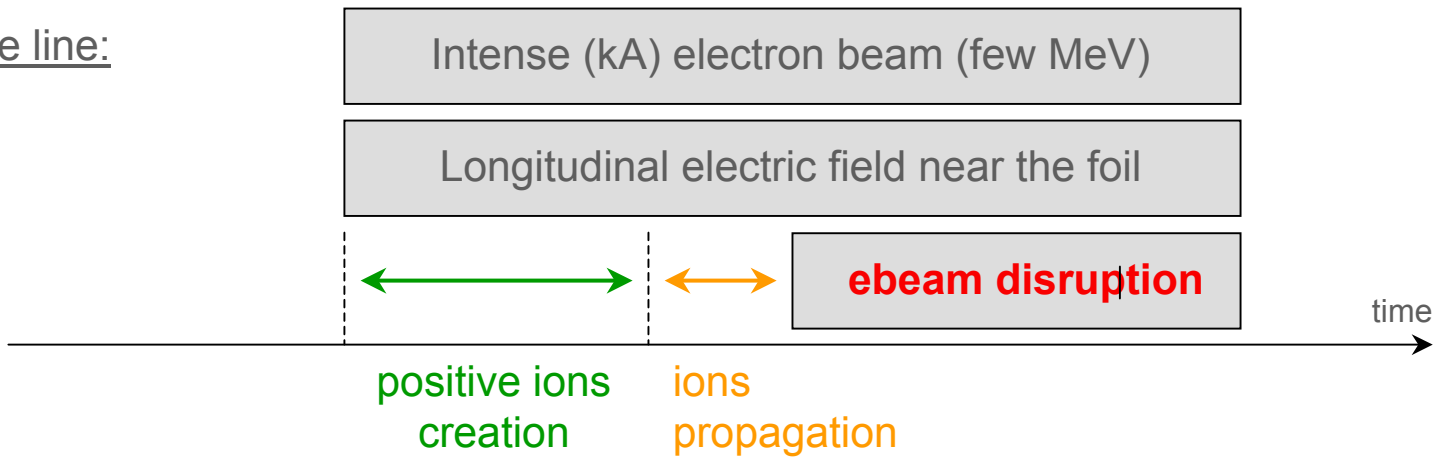
multiple pulse electron beam
2-4 kA, 20 MeV, 2000 ns
→ Active component of the transport

- The **ion creation process** is the focus of this study:
  - evaluation of the **primary current density threshold**
  - evaluation of the **starting time**

- Spatial view:



- Time line:



Time sequence before beam disruption

The number of positive ions needed to disrupt the primary electron beam is very small

~ 1/200 of a mono-layer

- ION LIBERATION PROCESS

  Electron impact induced desorption of ions and neutrals

  - **Thermal desorption of impurities** from the surface when the temperature reaches 400°C [*Stanford(1989)*] and ionization.

  - **Melting** (or sublimation for carbon) followed by ionization[*Kwan(2000)*]

Emission of H^+, H_2^+, $C_nH_m^+$, H_2O^+, CO^+, OH^+, etc…

Sensitive to target material

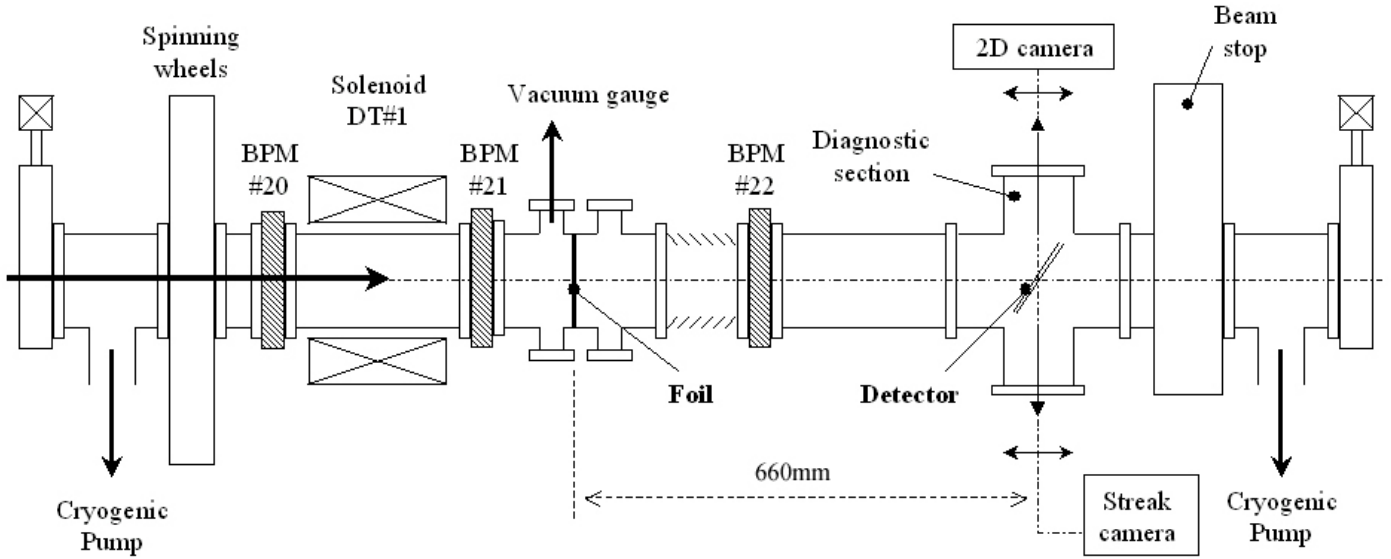
- IONS PROPAGATION inside the beam

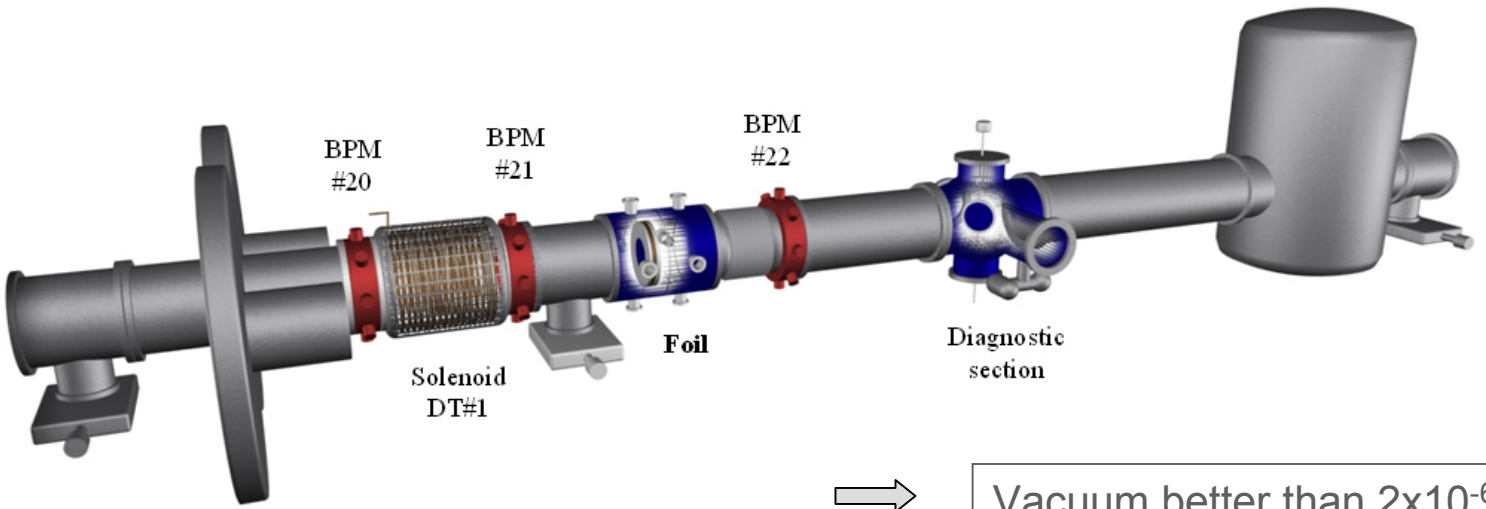
  - analytic models [Welch(1998), Chen(1998), Vermare(1999)]

  - **PIC code** (LSP…)

EXPERIMENTAL DELAY = LIBERATION + PROPAGATION

Experimental set-up

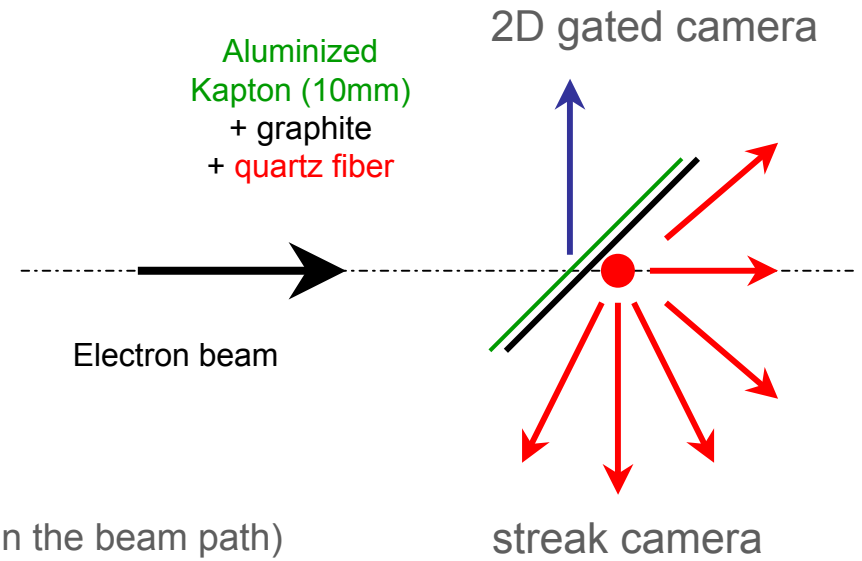




⇨ Vacuum better than 2×10^{-6} Torr

- Optical Transition Radiation

  - observes the beam position with respect to the fiber



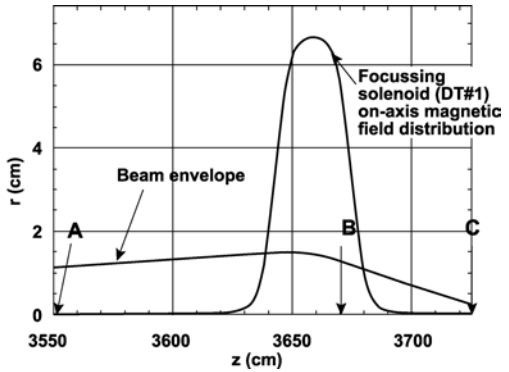
- "Cerenkov" light

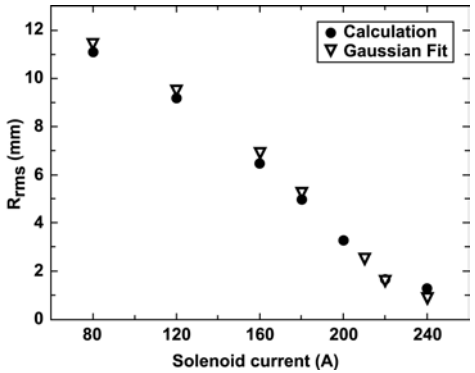
  - produced by a quartz fiber (placed vertically in the beam path)
  - imaged by a streak camera
  - gives the beam profile versus time

- « Beam Position Monitor » BPM

  - electron beam current
  - electron beam position

- Step #1 : ebeam parameters at the foil

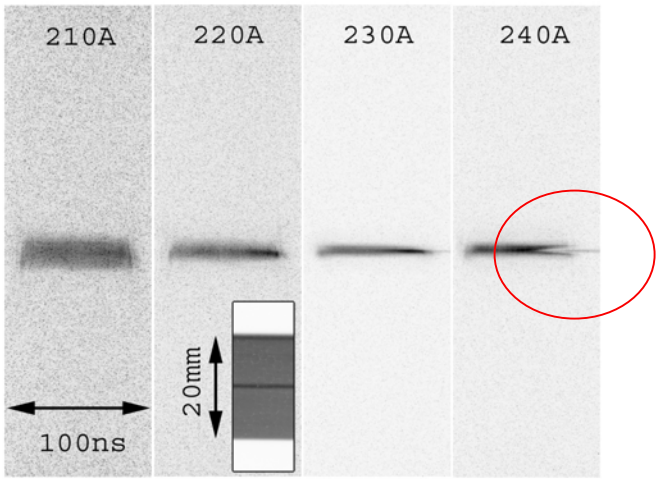




⇨ Tuning of the beam current density impinging the target

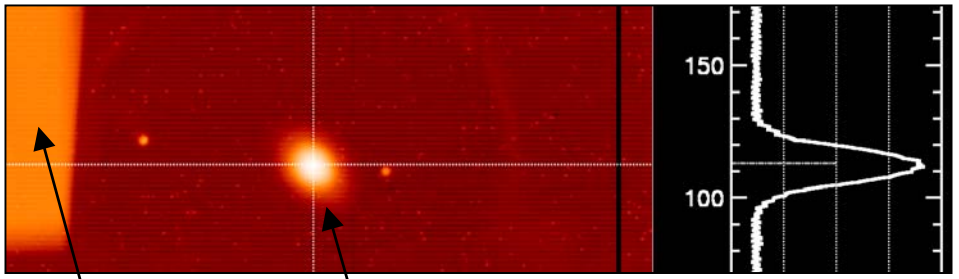
Range from 0.5A/mm^2 to 100A/mm^2

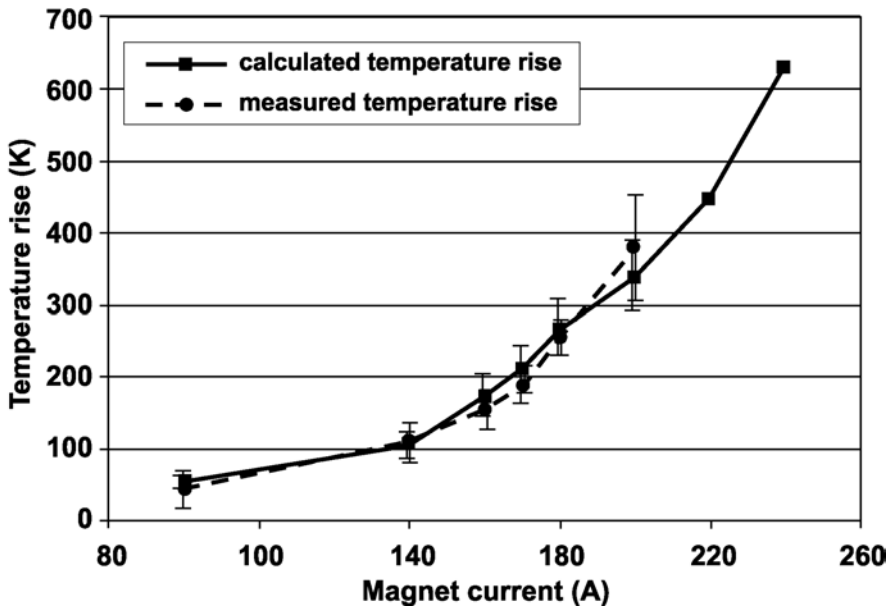
⇨ **Direct observation of the beam disruption**



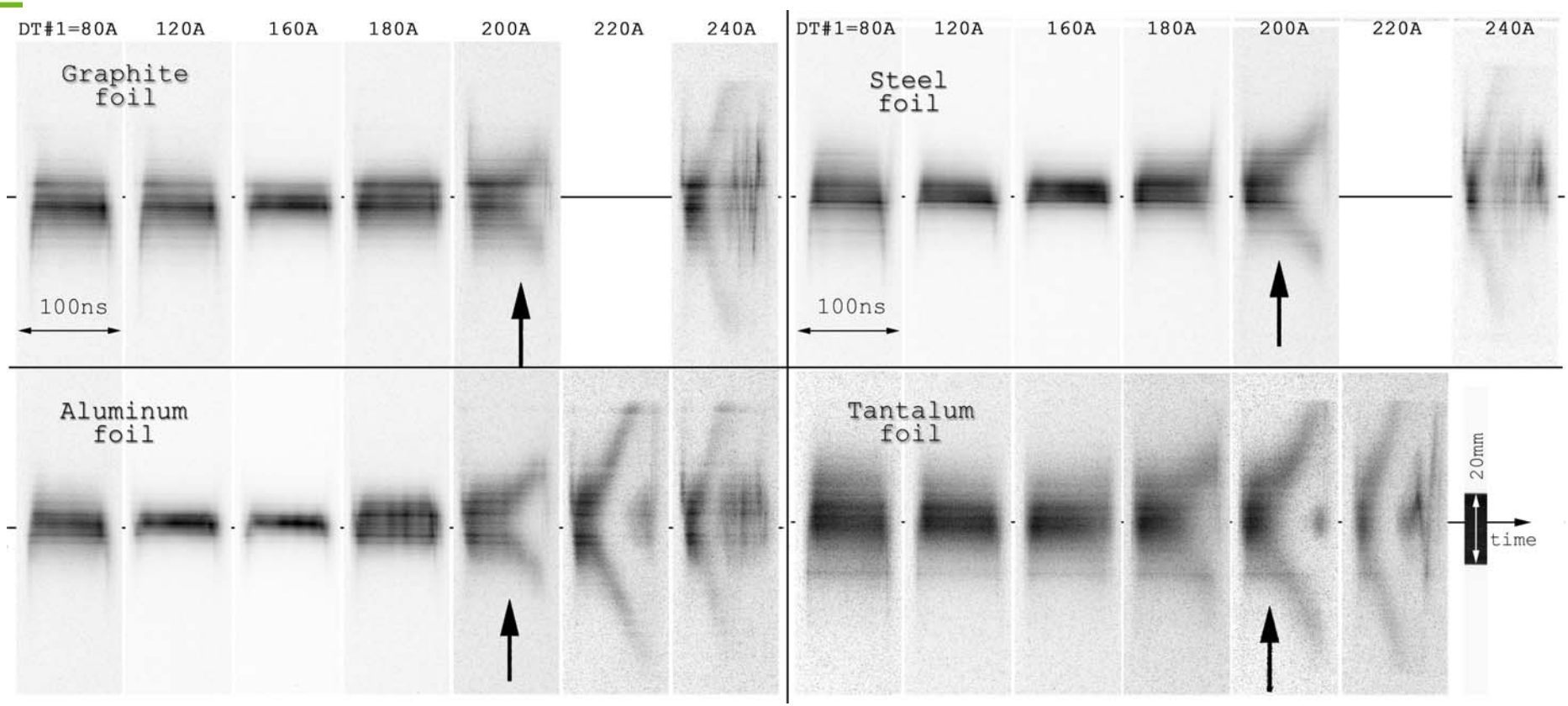
- Step #2 : temperature rise of the target surface – Thermal imaging

(Dave Simmons and Mark Wilke, LANL)





Example of Beam disruption results



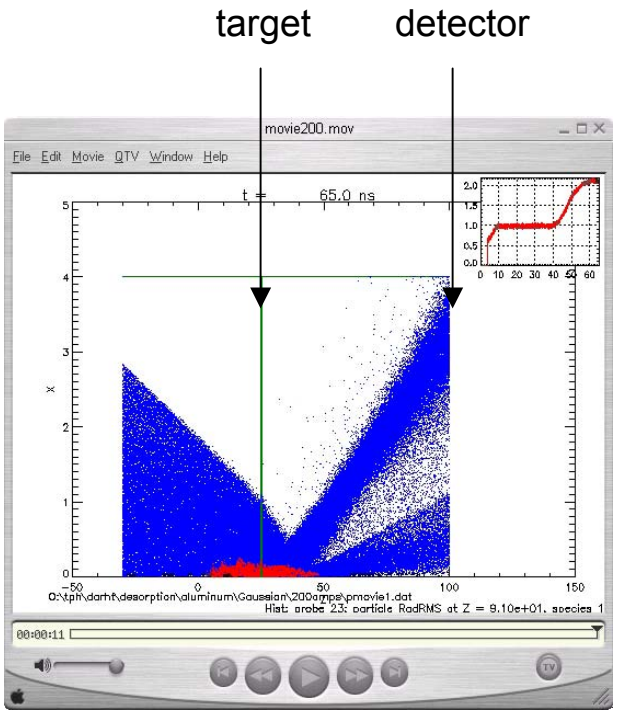
- Constant parts: - **consistent** with the **scattering / electrostatic** effects

- Variations versus time:
  - clear effects **starting sooner** with **higher beam current densities**
  - delays to reach the **melting** are **not consistent with the experiment**
  - delays to reach **400°C** are **compatible**
  - **growing oscillation** after beam expansion

LSP : the PIC code used for the experiment simulation

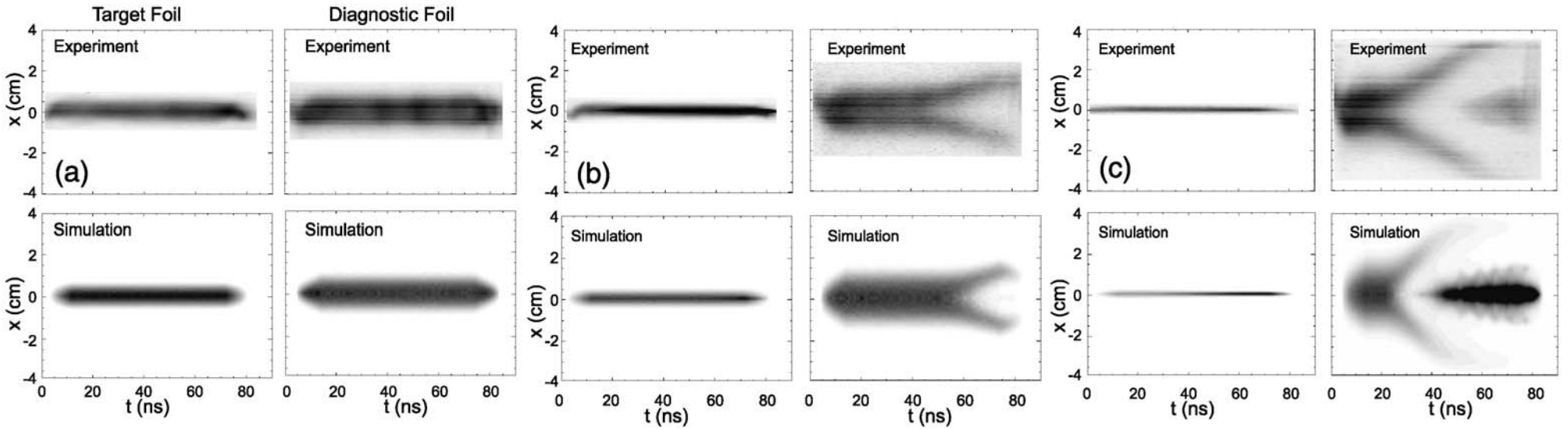
- Parallel (MPI) 2D-3D Particle-In-Cell code
- Direct implicit (FDTD) electromagnetic solver
- Multiple scattering produced inside the target
- Energy loss in material and surface heating
- Ions / Neutral release and ionization

- X-rays production, Kinetic-fluid hybrid electrons, RF absorption and materials, Coulomb collisions, …



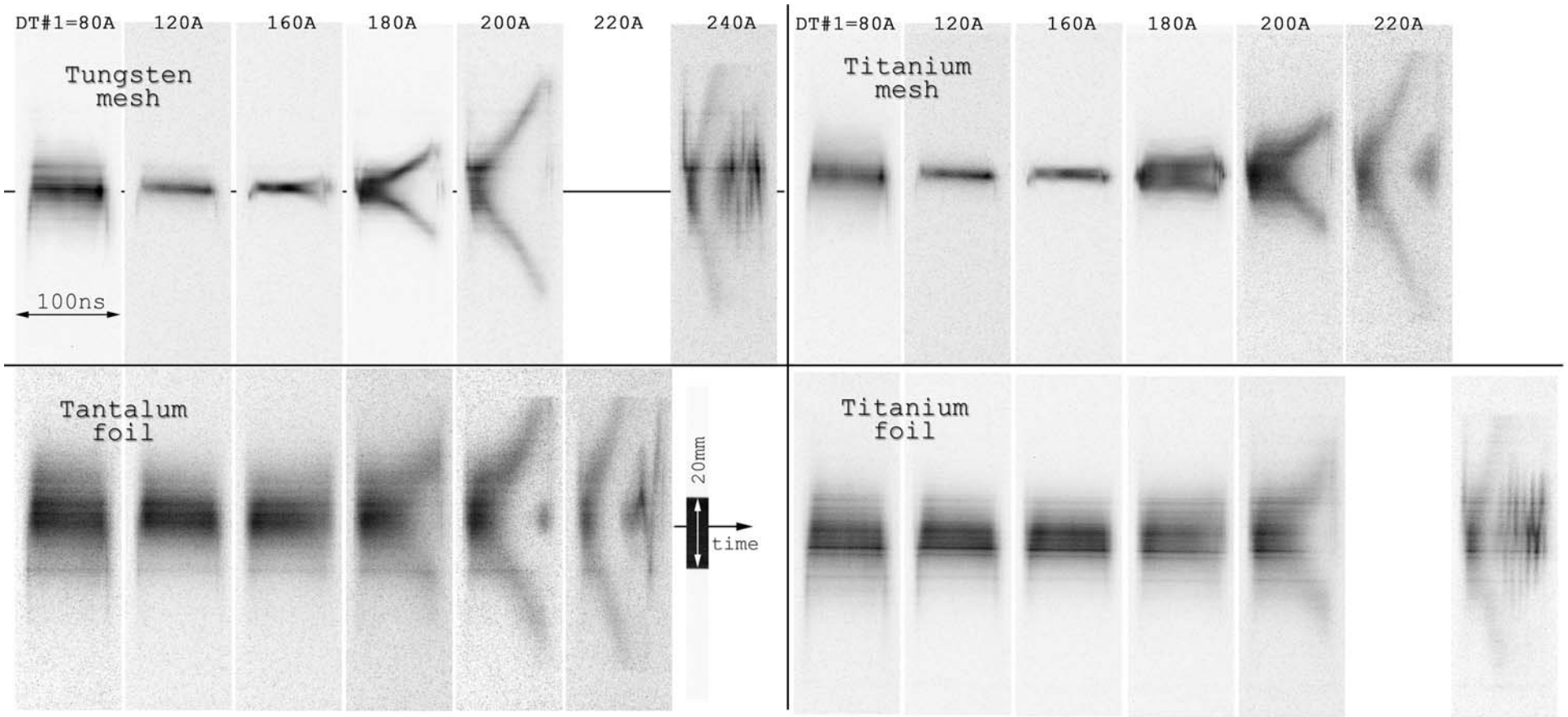
Blue dot => electron (main beam)
Red dot => ions emitted form the foil (H+ here)

DT#1 = 180A DT#1 = 200A DT#1 = 220A

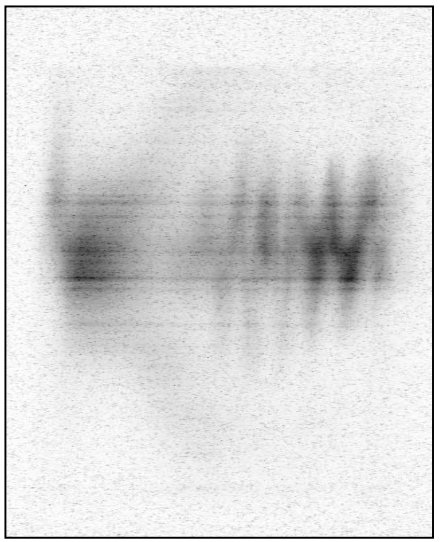


- **Space charge limited** emission of positive ions **from cracked water** (H+, H2O+, HO+, O+)
- From cracking/ionization cross section @20 MeV (9% of H+)
- **40% of the ion current is due to the H+**

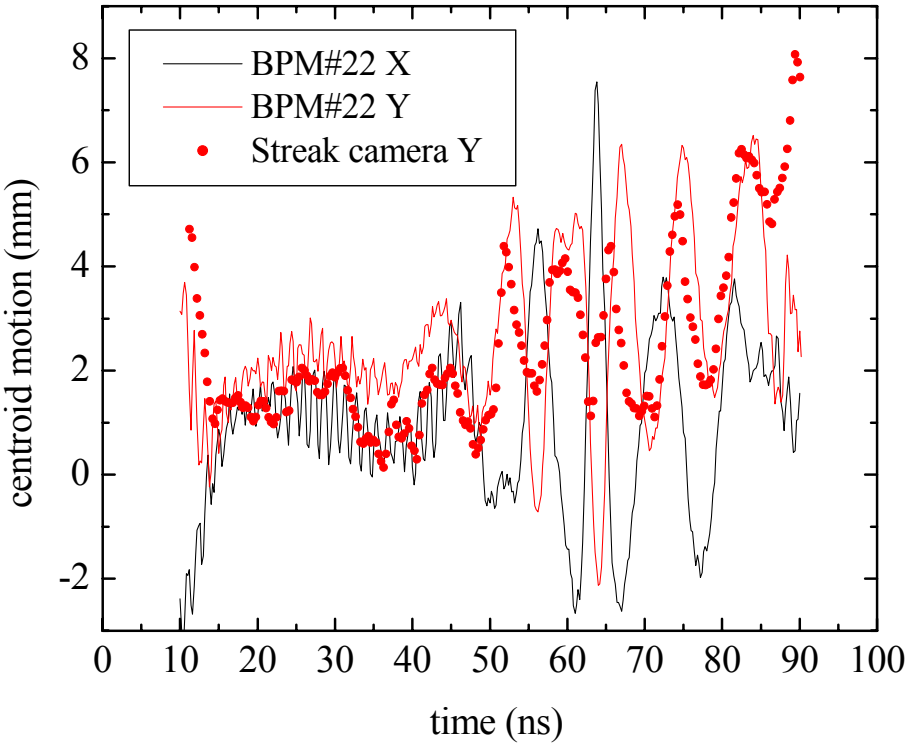
Difference between plain surface and 90% open meshes



- Scattering effect smaller with the meshes
- **No significant difference** in the time dependence
- **Enough ions available for space-charge limited current with a surface 10 times reduced**



Frequency = 125 +/- 10 MHz
Amplitude = 6 ±3 mm peak-to-peak

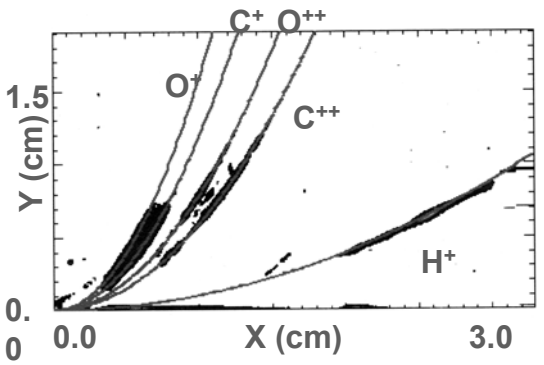


- **Consistent results** from the **BPM (electric)** and the **streak (optical)**
- **Agrees with PIC simulation with H+ !**

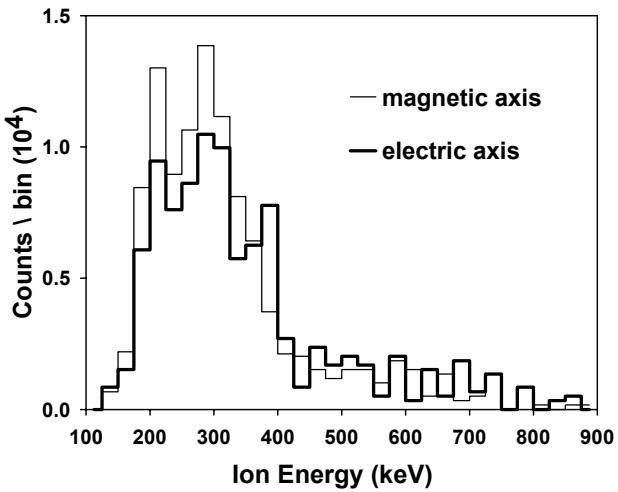
Frequency = 140 MHz
Amplitude = 2 mm peak-to-peak

In going experiment using a Thomson spectrometer

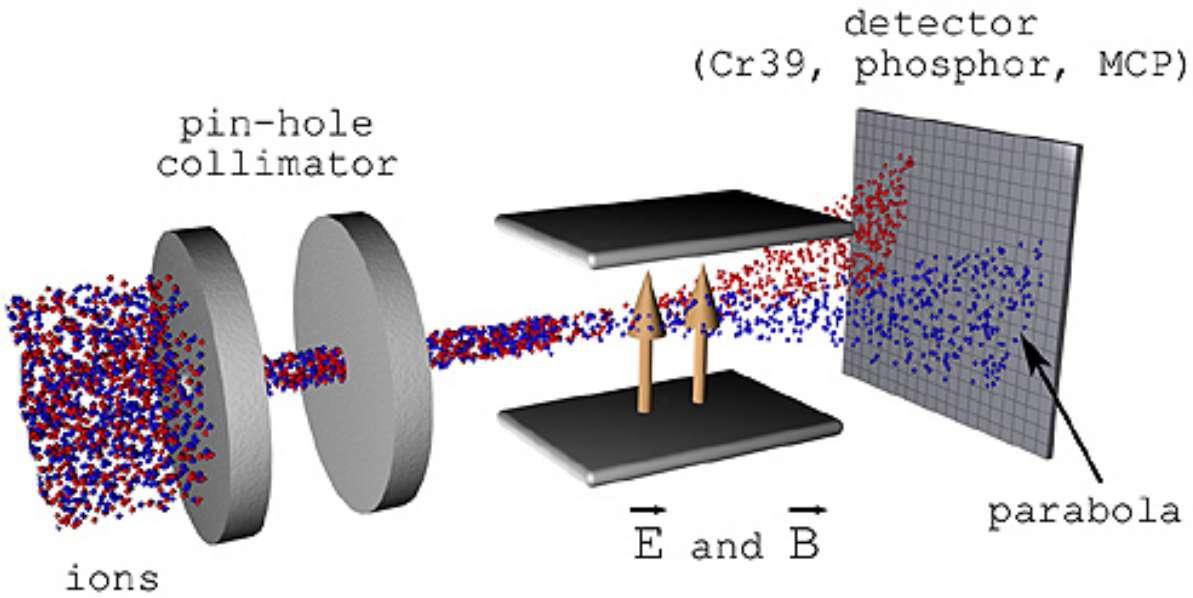
Typical raw data



Typical spectra (H^+)



Spectrometer configuration



This experiment will be able to confirm the **nature of the ions**

Conclusion

- The **experiment set-up using the two foils techniques is well adapted**
  - large effect on the beam dynamic
  - time-resolved beam size measurement

- Simulations using **LSP** reproduced the **observation made on the beam dynamic**
  - the radial profile behavior is comparable
  - the transverse oscillation is confirmed

- Information on the **ion creation process**:
  - the melting temperature doesn't need to be reached !
  - the induced neutral desorption and following ionization exist
  - **but only a thermal threshold can explain the abrupt change !**
  - **Cracked water molecule seems to be the main source of ions**
  - **Presence of a significant part of H+**