



Deceleration of H-like uranium ions in a crystal (in channeling conditions)

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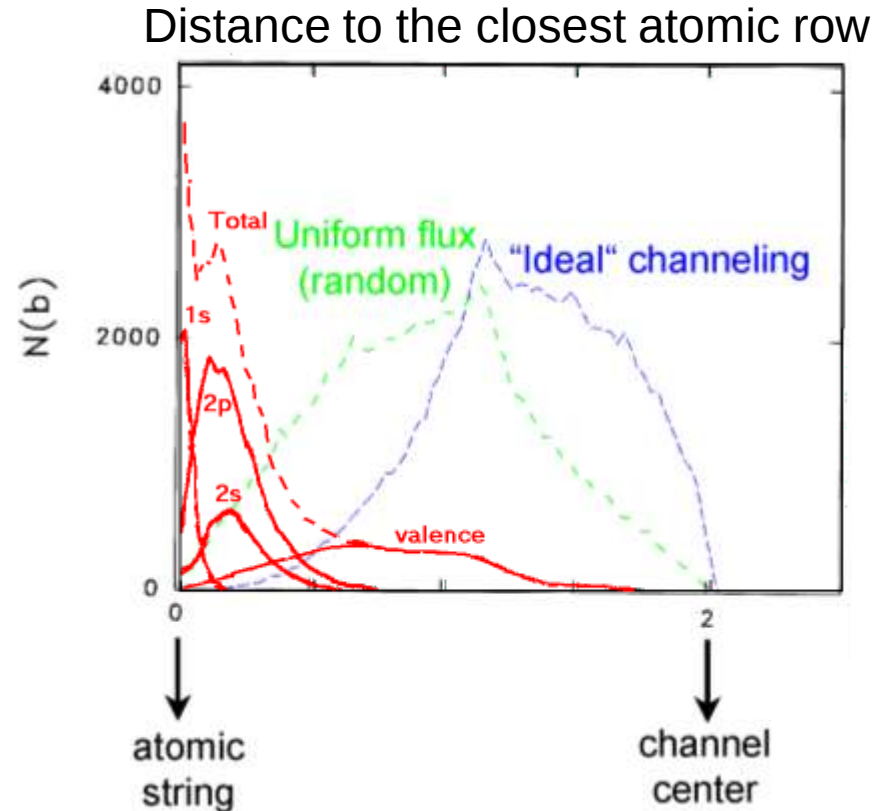
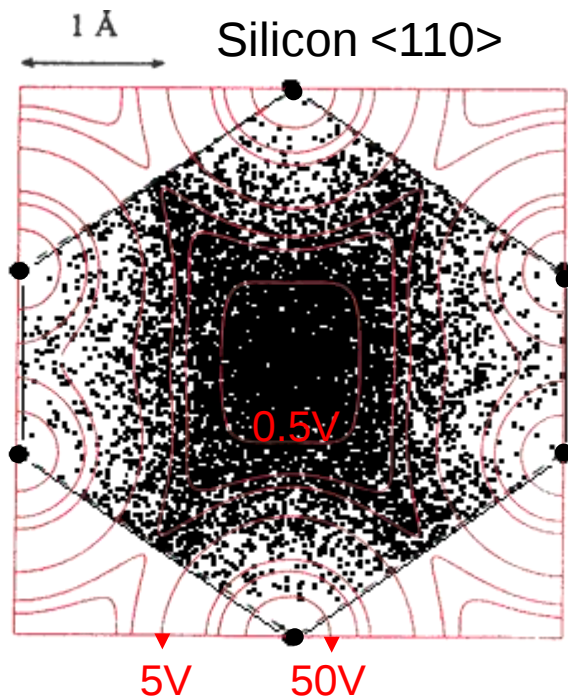
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Outline

1. Ion flux in channeling
2. Capture processes
3. Experimental set-up
4. Experimental results
5. Conclusion

Interaction with a non uniform electron gas



Flux redistribution at equilibrium

⇒ Interaction with valence electron

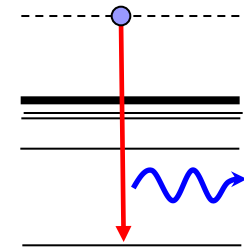
Reduced electron density

⇒ Reduced energy loss ($\sim$ factor 2)

Charge exchange by channeled ions

Interaction with a quasi free electron gas :

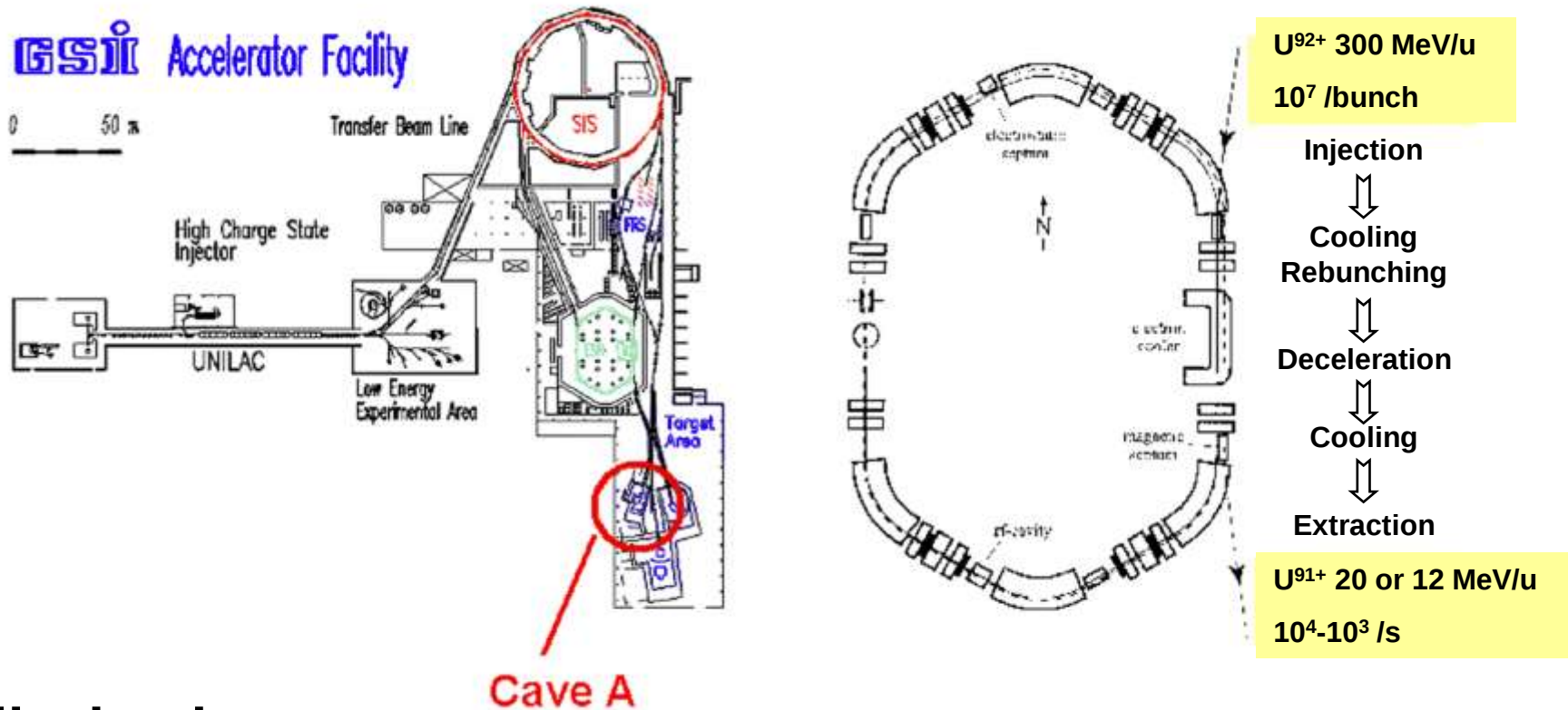
- Radiative Electron **Capture** (REC) :
 - Energy and momentum balance $\Rightarrow$ photon
(inverse of photoelectric effect)
- Electron Impact **Ionization**



Extinction of close collisions processes :

- Mechanical Electron **Capture** (MEC) : non radiative capture
 - 3-body capture (target recoil)
- Nuclear Impact **Ionization**

The ESR storage ring at GSI



H-like ion beams:

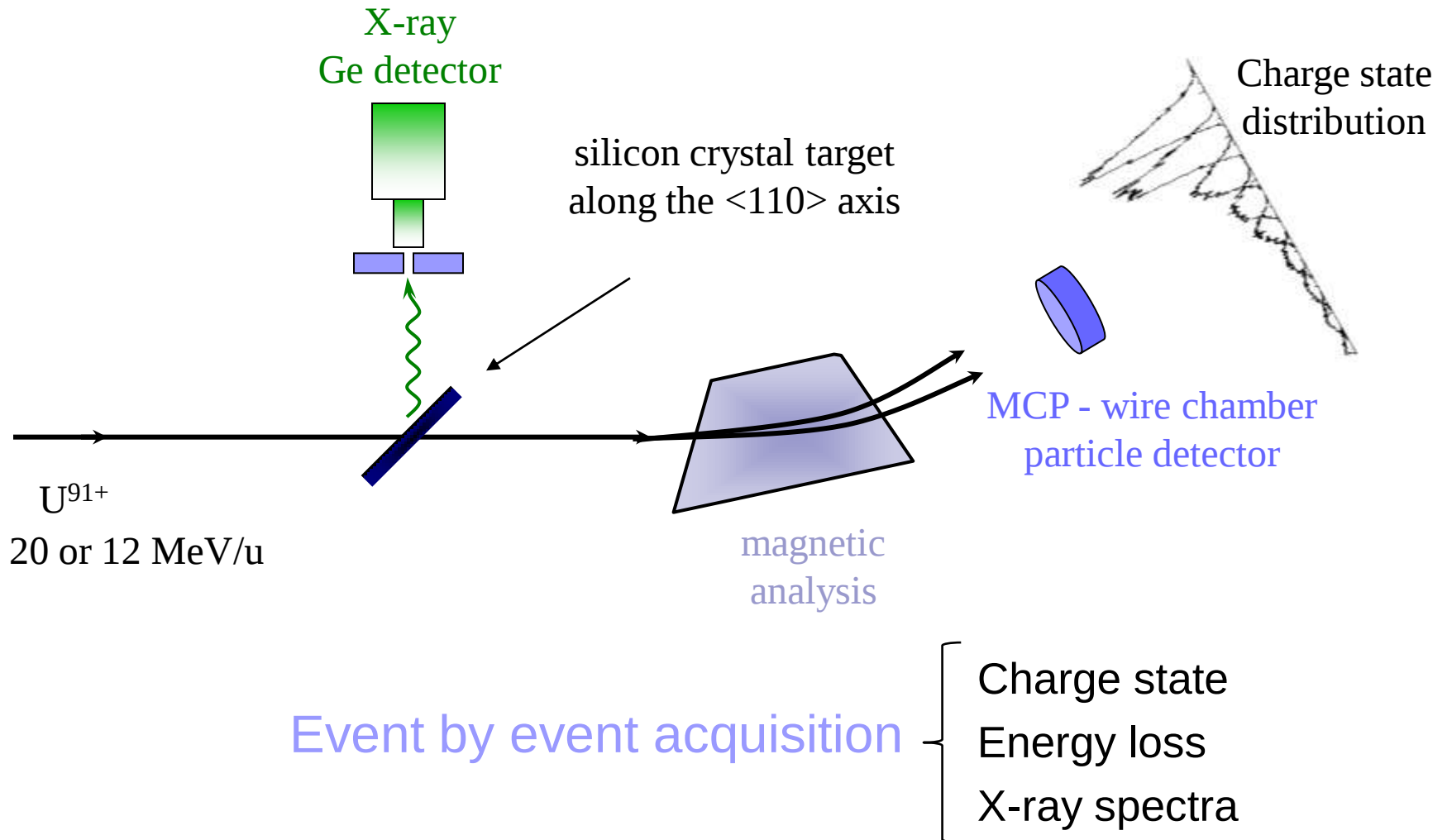
U^{91+} 20 MeV/u (2001)

U^{91+} 12 MeV/u (2005)

$$\eta_K = \frac{v}{v_K} \approx 0.085, \eta_L \approx 0.35, \eta_M \approx 0.8$$

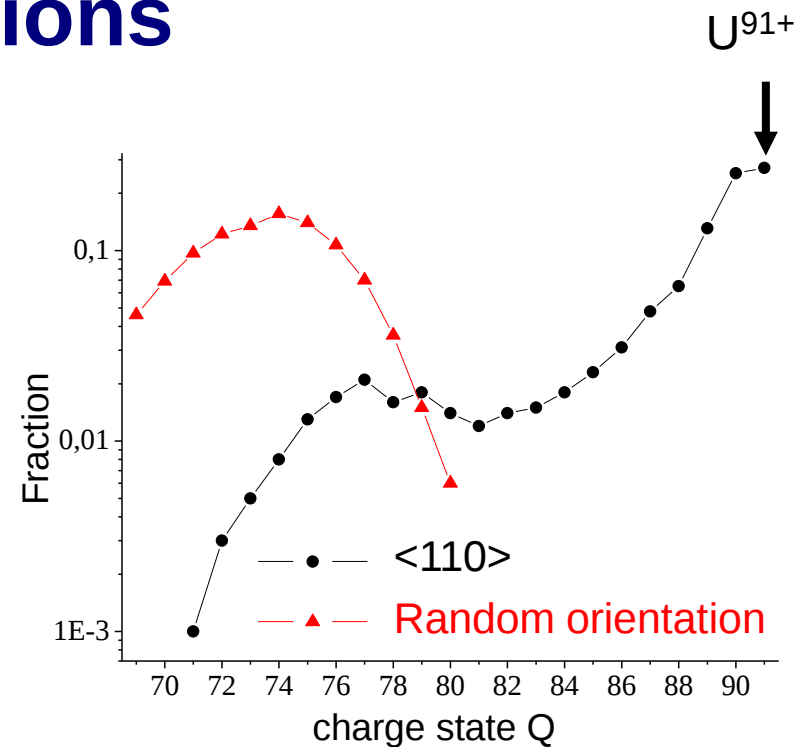
⇒ Far from charge equilibrium in matter

Experimental setup scheme Cave A beam line



Charge state distributions

U^{91+} 20 MeV/u $\rightarrow$ 11.7 μm Si

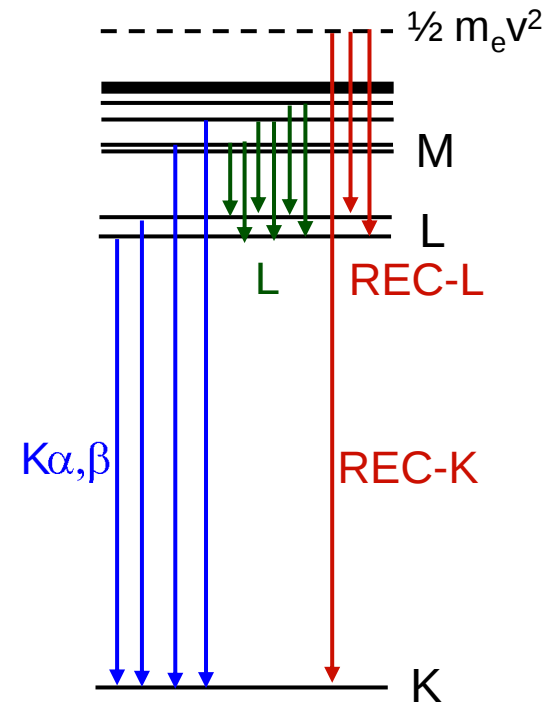
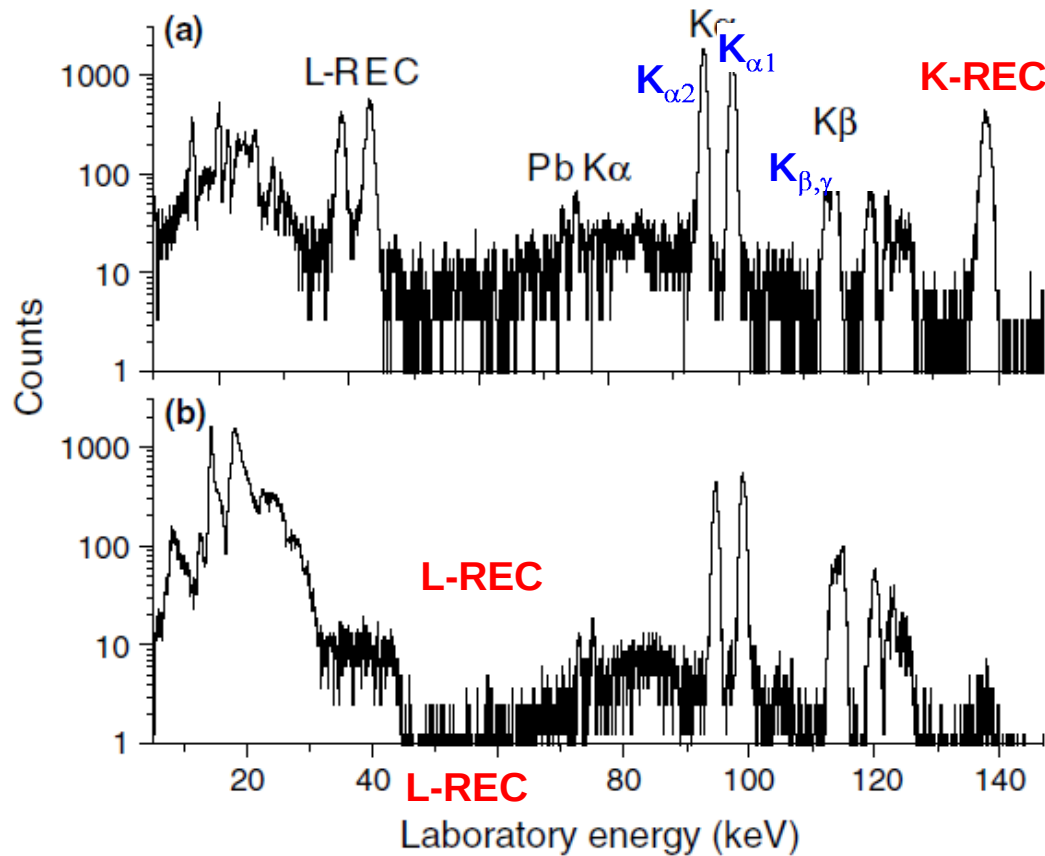


- **Random orientation** : MEC and NII dominate $\Rightarrow$ charge equilibrium
- Axial orientation : $F(Q_{\text{out}})$ connected to $F(E_{\perp})$
 broad distributions
 Axis <110> : 30% of frozen ions ($Q=91+$)

X-ray spectra (90°)

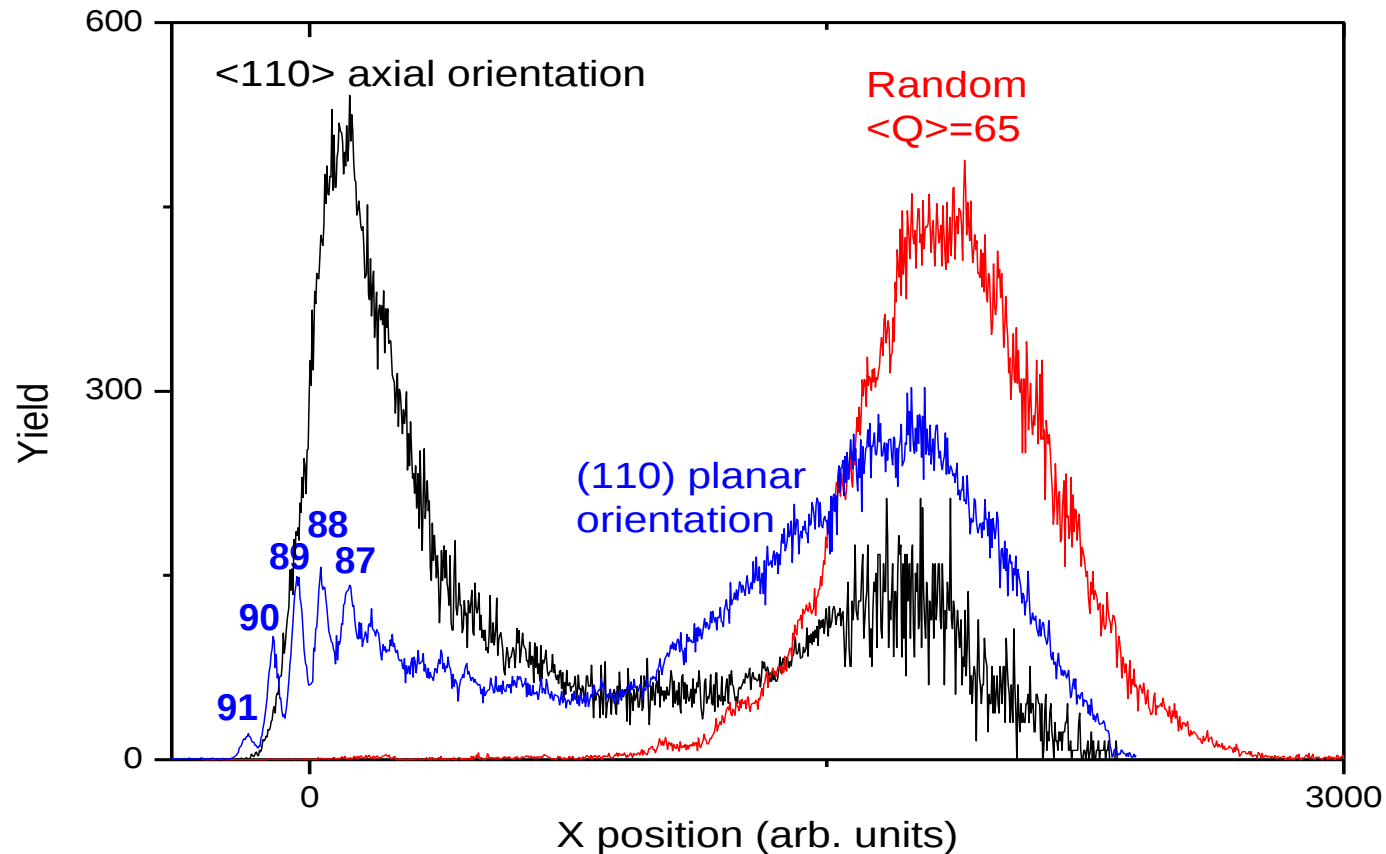
U^{91+} 20 MeV/u $\rightarrow$ 11.7 μm Si

L-lines



Charge state distributions

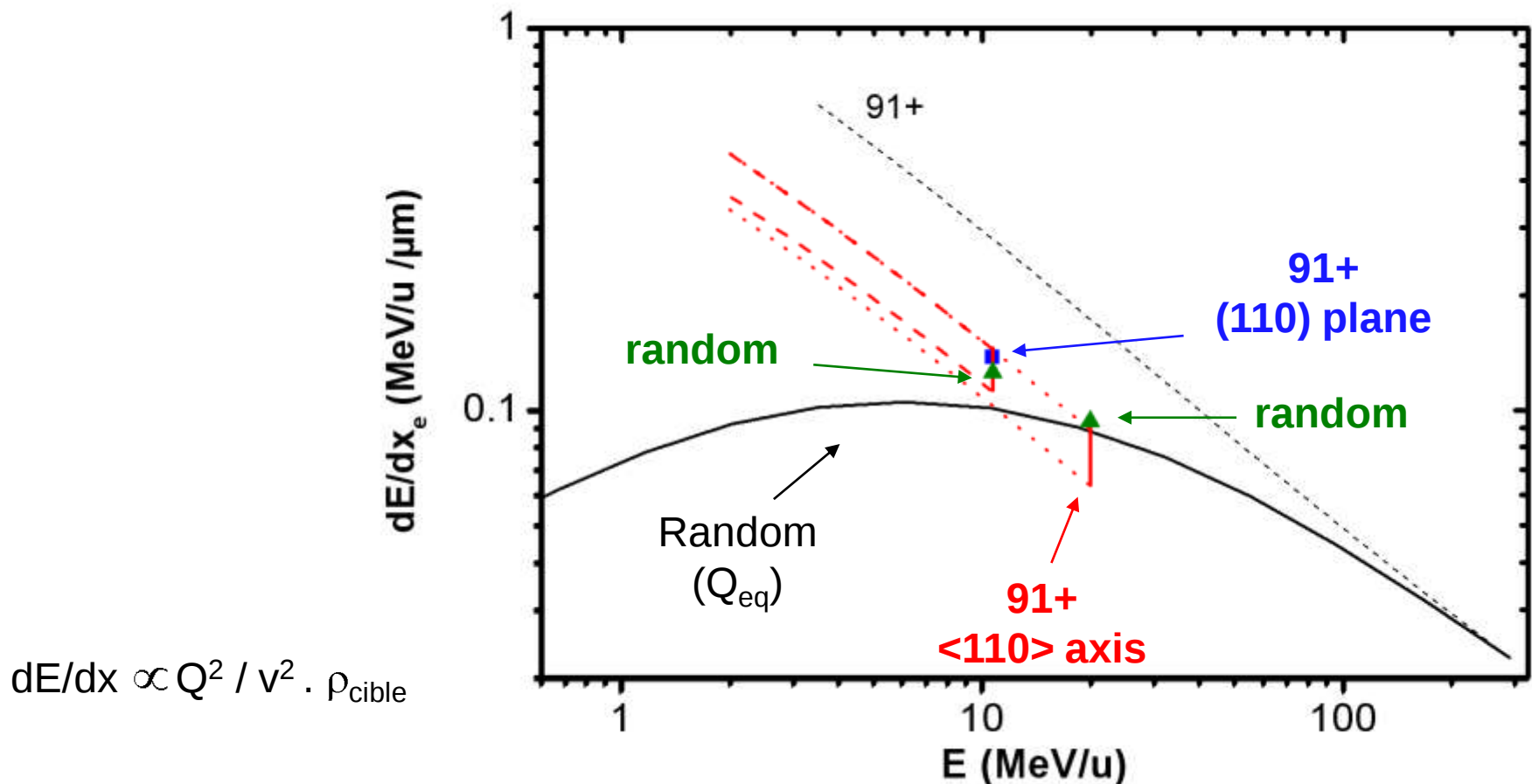
U^{91+} 12 MeV/u $\rightarrow$ 18.3 μm Si



Frozen transmitted U^{91+} ions

~ 0.3% for (110) planar channeling
~ 1 % for <110> axial channeling

Deceleration of highly charged U ions



energy loss @ 20 MeV/u : $\Delta E_{\text{axial}} = [0.75-1] \text{ MeV/u} \sim \Delta E_{\text{random}} = 1 \text{ MeV/u}$

energy loss @ 12 MeV/u : $\Delta E_{\text{planar}} = 2.55 \text{ MeV/u} > \Delta E_{\text{random}} = 2.3 \text{ MeV/u}$

For $E < 15 \text{ MeV/u}$: $dE/dx (\text{channeled } U^{91+}) > dE/dx (\text{random})$

Conclusion

- *High energy loss rate $\Rightarrow$ crystal decelerator*
 - Deceleration of U^{91+} from 12 to 9.45 MeV/u in a 18 μm thick crystal
 - Test for stopping power theory at very high perturbation regime

 - Channeling of highly charged, slow heavy ions
 - *Detailed study of charge exchange as a function of impact parameter*
 - MEC: capture into high n-shells far from atomic strings
 - REC: probe for the dynamic electron gas polarization
- Wake effect : E. Testa et al. NIMB 245 (2006) 47**
-
- Future $\rightarrow$ FAIR (SPARC collaboration)

Collaboration

- IPN Lyon

- M.Chevallier, D.Dauvergne, R.Kirsch, J-C.Poizat, C.Ray, E.Testa

- GSI Atomic Physics

- F.Bosch, A.Bräuning-Demian, H. Bräuning, A.Gumberidze, C.Kozhuharov, D.Liesen, P.Mokler, Th.Stöhlker, M. Tarisien, S.Toleikis, P.Verma

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- C.Cohen, A.L'Hoir, J.-P. Rozet, D. Vernhet

- CIRIL Caen

- M.Toulemonde

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