Hybrid Electrostatic Ion Beam Trap (HEIBT): Towards merged beam experiments.

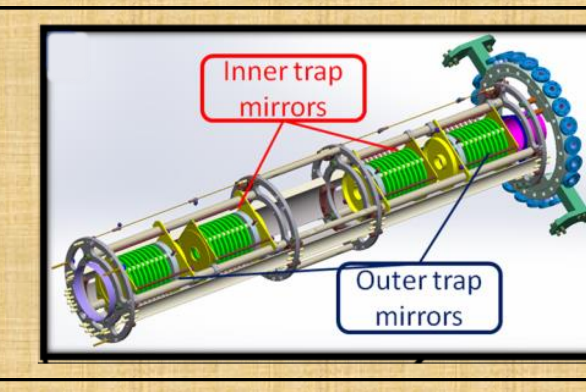
A. Bogot,[1] A. Shahi,[(1,2)] M. L. Rappaport,[(2)] O. Lioubashevski,[(1)] O. Heber,[(2)] D. Zajfman,[(2)] and D. Strasser[(1)].

[1]The Hebrew University of Jerusalem, Institute of Chemistry, Jerusalem 91904, Israel
[2]Weizmann Institute of Science, Department of Particle Physics and Astrophysics, Rehovot 7610001, Israel

Introduction:

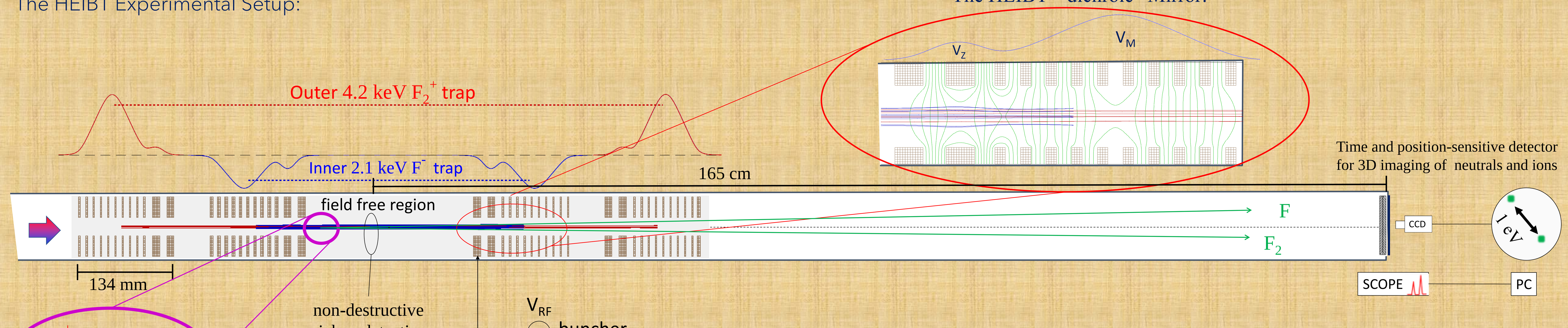
- We present the HEIBT that implements dichroic mirrors for simultaneous trapping of velocity matched, merged cation and anion beams.[1,2]
- Similar to the "Zajfman" trap,[1] lighter ions are trapped between the inner set of electrostatic mirrors,[1] while the heavier ions oscillate between the outer mirrors and pass through the inner HEIBT mirrors.
- First experimental ion trapping tests successfully exhibit long, over ~1sec trapping lifetime for the outer trap ion trajectories that pass "through" the inner set of mirrors.
- The HEIBT will allow a wide range of ion-ion, ion-neutral and ion-laser studies.
- For example : Mutual neutralization (MN) experiments as a function of the collision energy and internal ion excitation of molecular and cluster ions.

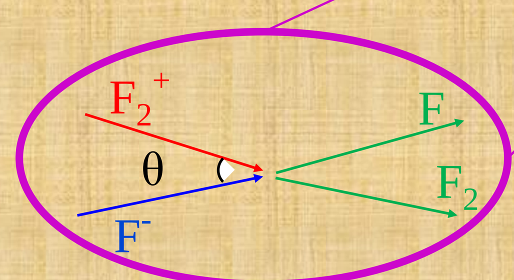
$AB^- + C^+ \rightarrow ABC^* \rightarrow A + BC$ (or $\rightarrow A + B + C$)



The HEIBT Experimental Setup:

The HEIBT "dichroic" Mirror:



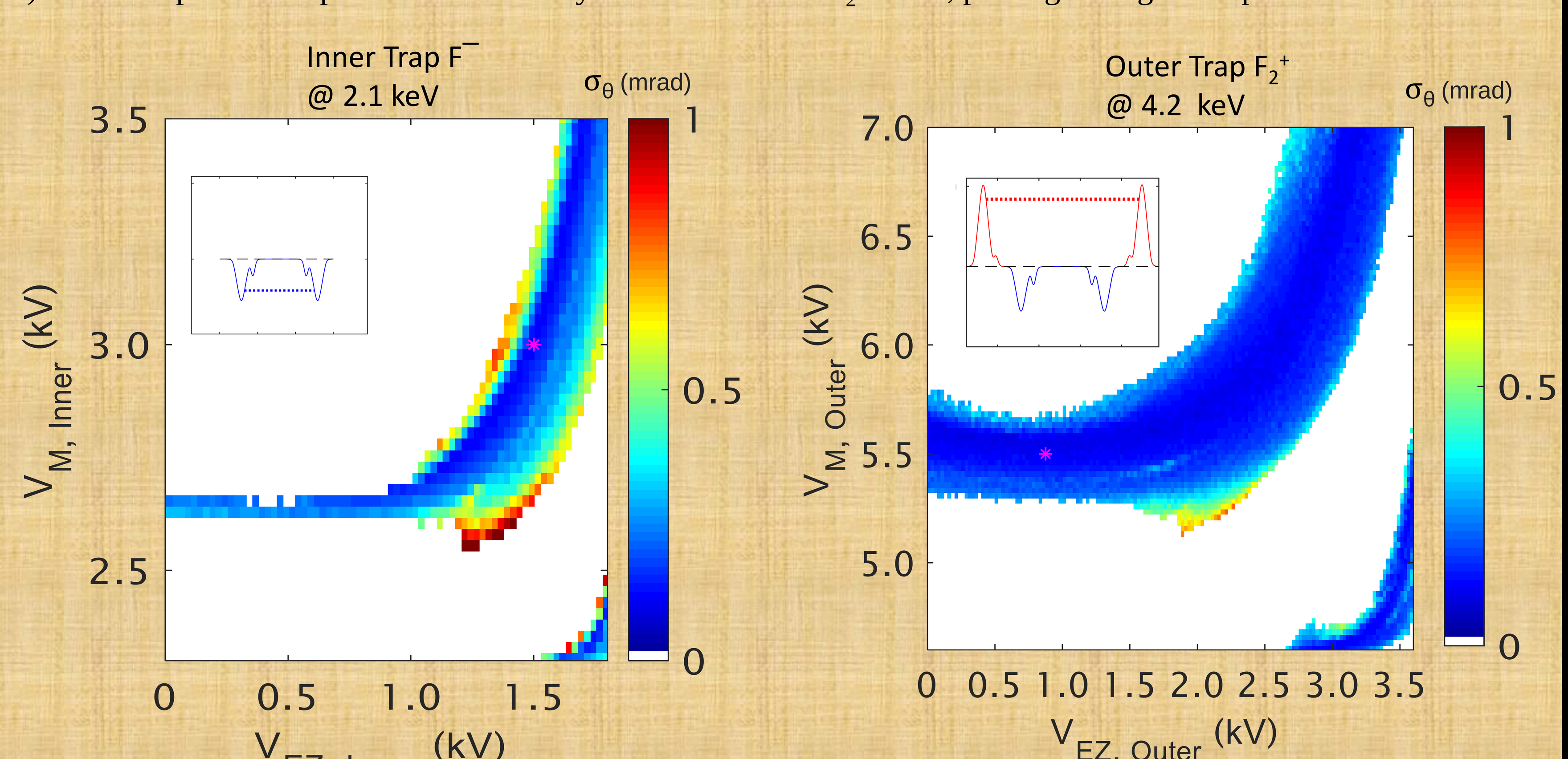


$$\Delta E_{col} \approx \Delta E\left(\frac{\Delta E}{\sqrt{E_1 E_2}}\right)\left(1-\frac{\mu}{m_1+m_2}\right) + \Delta\theta^2 \mu V_0$$

- Similar to single-pass experiments and the double storage ring DESIREE,[3,4] fragment imaging will allow final state detection.
- Long trapping lifetimes will allow to study ions as a function of their internal temperature.[1]

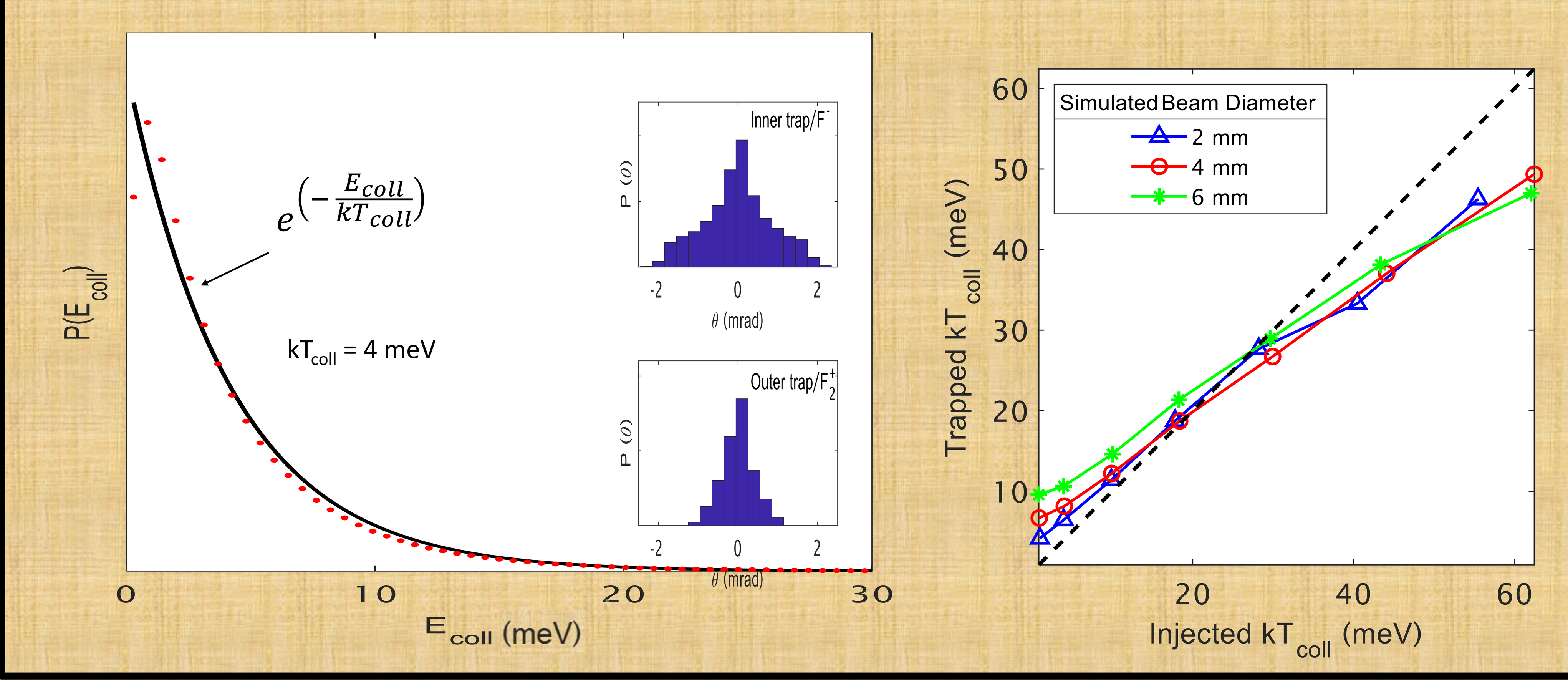
SIMION optimization of the HEBIT mirrors:

1) Inner trap for a 2.1 keV F^- beam, optimized for trapping efficiency & angular spread in the field free region.
2) Outer trap mirrors optimized for velocity matched 4.2 keV F_2^+ beam, passing through the optimal inner mirrors.



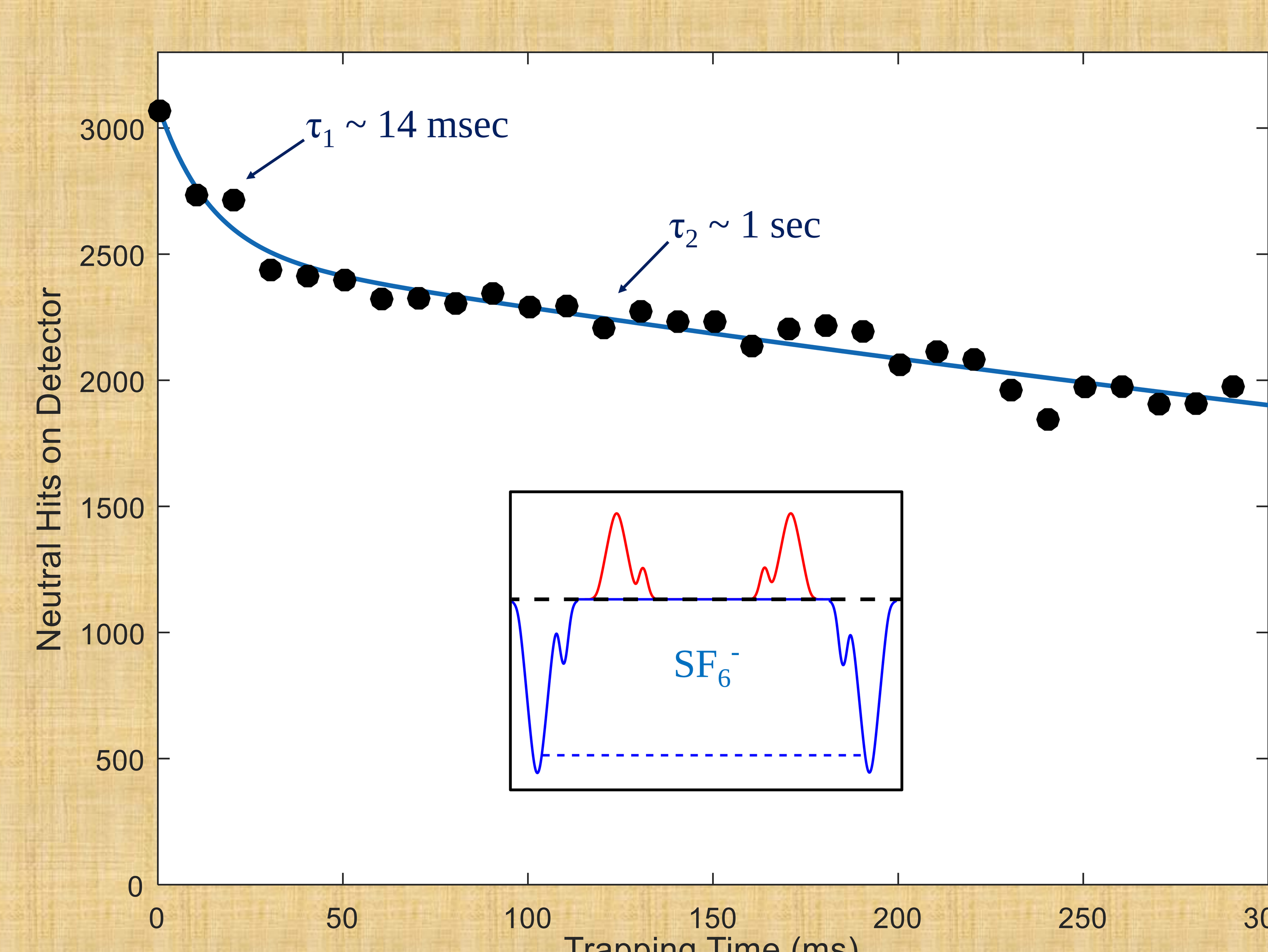
Optimal field free collision temperatures:

1) Simulated collisions in the field free region fitted with a collision temperature
2) The collision temperature is mainly limited by the diameter and angular spread of the injected beam



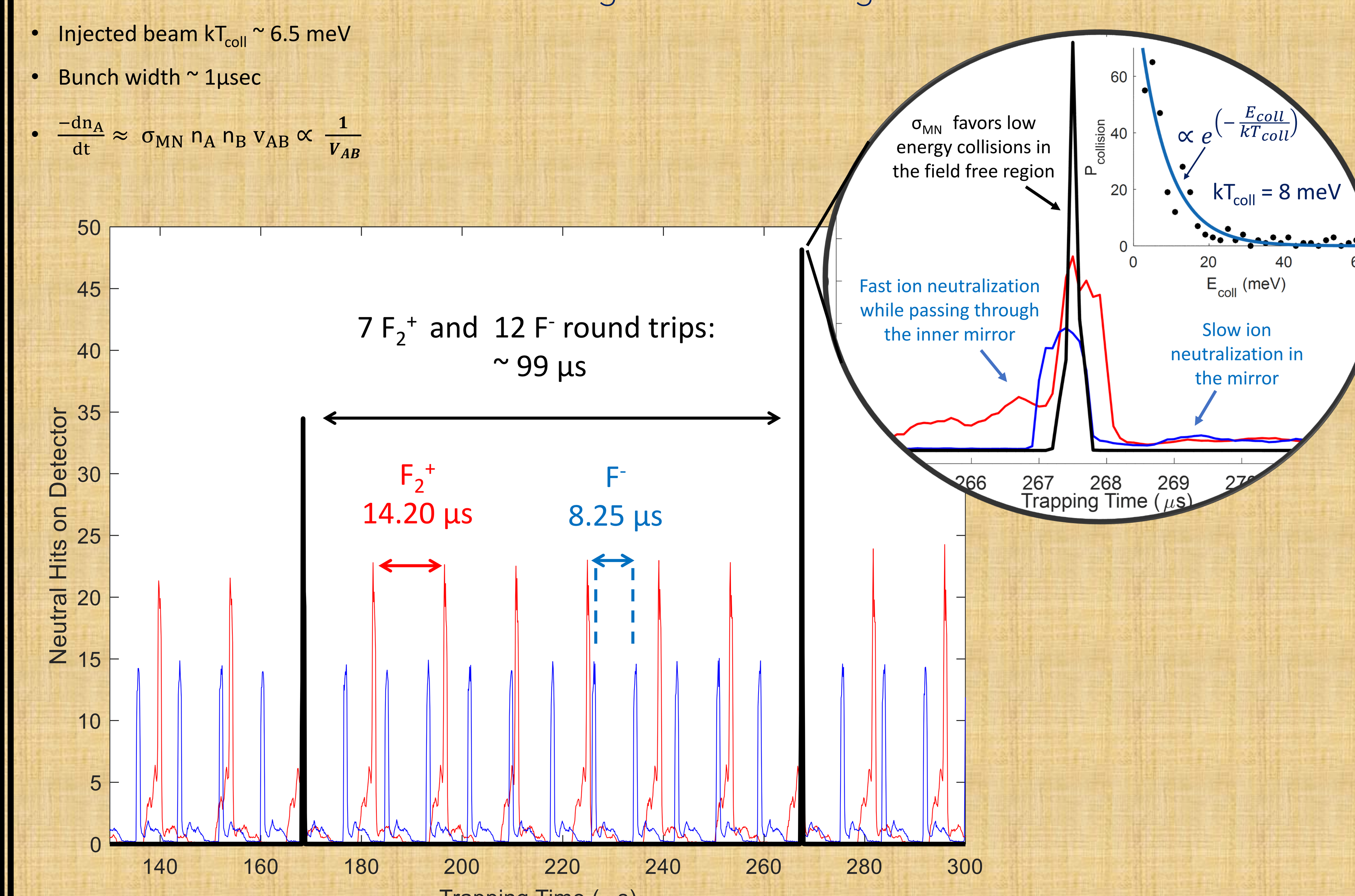
First experimental validation:

- Long trapping achieved in the outer trap, through the inner trap mirrors.
- Demonstrated by trapping an SF_6^- beam.
- The initial short lifetime is attributed to the decay of hot SF_6^- ions.



Realistic bunch mode simulation of merged beams MN signal:

- Injected beam kT_{coll} ~ 6.5 meV
- Bunch width ~ 1μsec
- $\frac{-dn_A}{dt} \approx \sigma_{MN}\, n_A\, n_B\, v_{AB} \propto \frac{1}{v_{AB}}$



Summary and Outlook:

- SIMION simulations show that HEIBT merged beam allows sub-eV energy resolution.
- Long (~1sec) trapping lifetime, experimentally validates the simulated "dichroic" mirror performance.
- The next merged beam systems to be studied are:
- $F^- + F_2^+$ as well as $F^+ + F_2^-$ MN reactions, expected to exhibit three-body as well as two-body breakup dynamics.
- Mutual neutralization of size selected clusters, e.g. $(H_2O)_nNO_2^+ + (H_2O)_mNO_3^-$, MN of micro-solvated ions.
- Benchmark $H^- + HD^+(v)$ collision studies as a function of collision energy and internal excitation.

References:

[1] D. Zajfman, O. Heber, L. Vejby-Christensen, I. Ben-Itzhak, M. Rappaport, R. Fishman, and M. Dahan, Phys. Rev. A 55, R1577 (1997).
[2] A. Shahi, R. Singh, Y. Ossia, D. Zajfman, O. Heber, and D. Strasser, Rev. Sci. Inst. 90, 113308 (2019).
[3] N. De Ruette, *et al.*, Phys. Rev. Lett., 121:083401 (2018).
[4] Gustav Eklund, *et al.* Phys. Rev. A., 102 , 012823 (2020).

Funding:
"F.I.R.S.T." BIKURA project, ISF, as well as Wolfson Foundation.