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Neutral Particle Analysis in Inertial Electrostatic Confinement Fusion Devices

Gabriel E. Becerra*, Gerald L. Kulcinski,
John F. Santarius, Gilbert A. Emmert

University of Wisconsin–Madison
** Presently at Phoenix Nuclear Labs*

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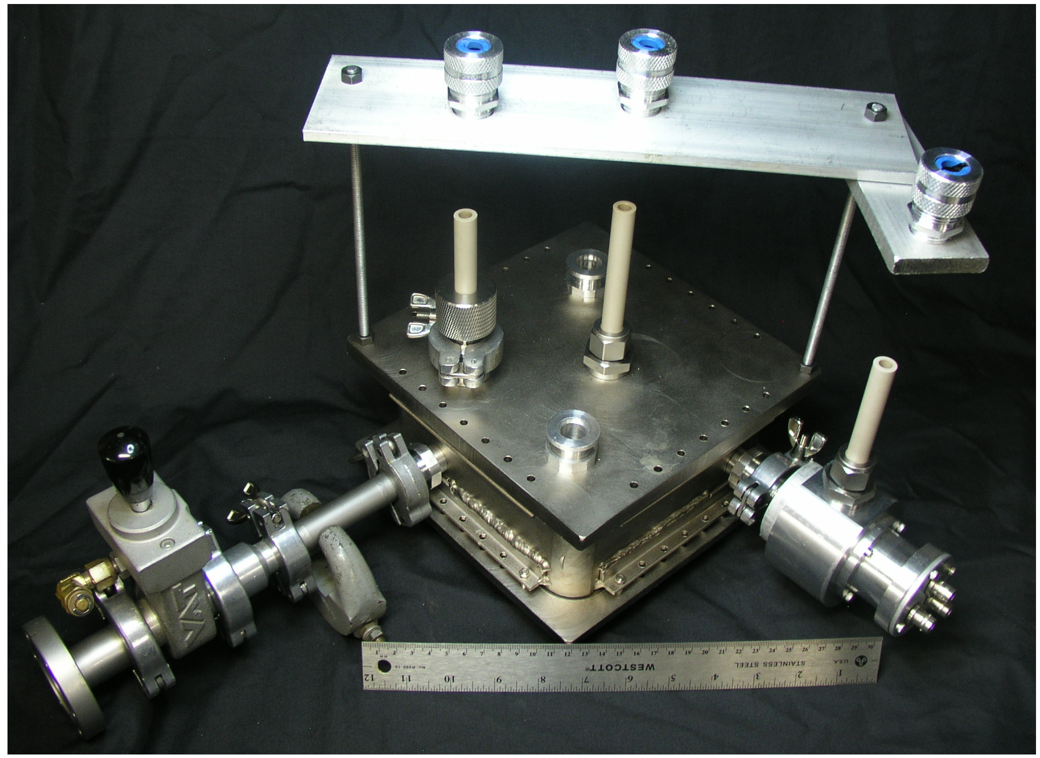
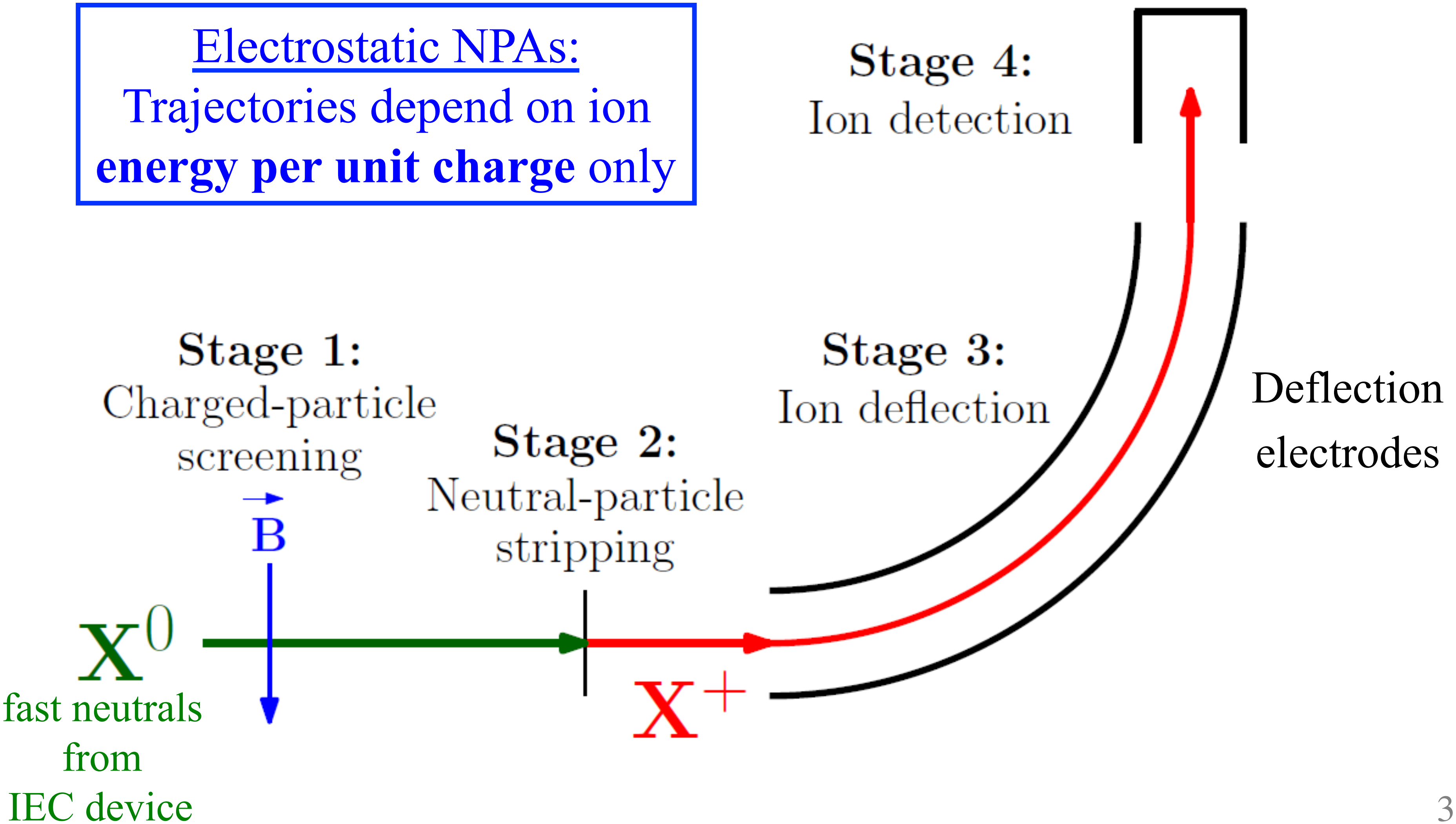
Direct analysis of escaping fast neutral particles has been performed on IEC devices for the first time



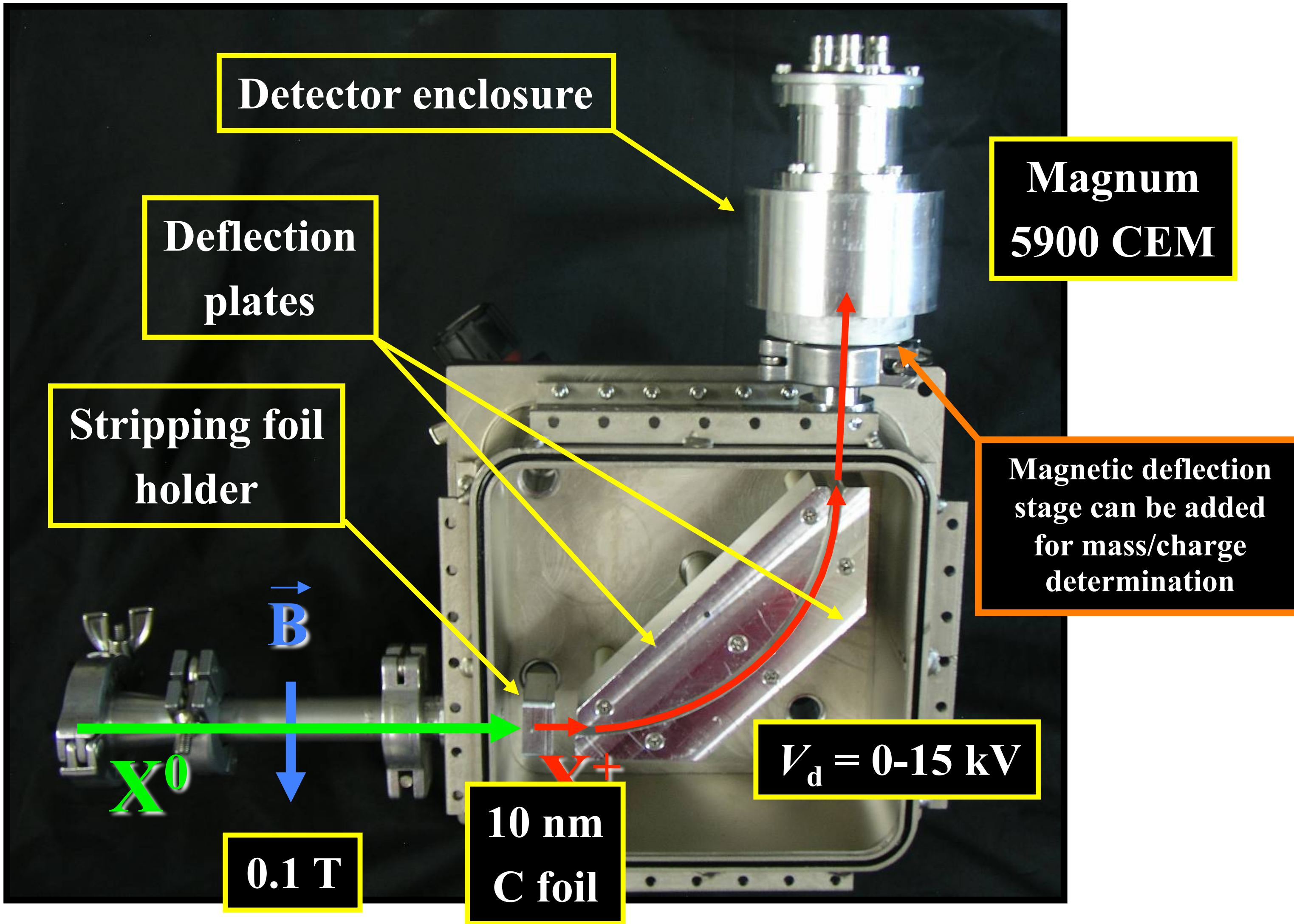
- A neutral particle analyzer (NPA) was designed and constructed specifically for IEC studies.
- New way to study IEC physics, especially with relevance to ^3He-^3He fusion:
    - Much better statistics, shorter data acquisition than fusion-product-collecting diagnostics;
    - Allows for relevant experiments with helium-4 instead of helium-3;
    - Greatly relaxes the high-voltage requirements.
- Fast-neutral energy spectra can yield line-of-sight-averaged ion energy distribution functions.

An electrostatic neutral particle analyzer (NPA) was engineered with modularity in mind

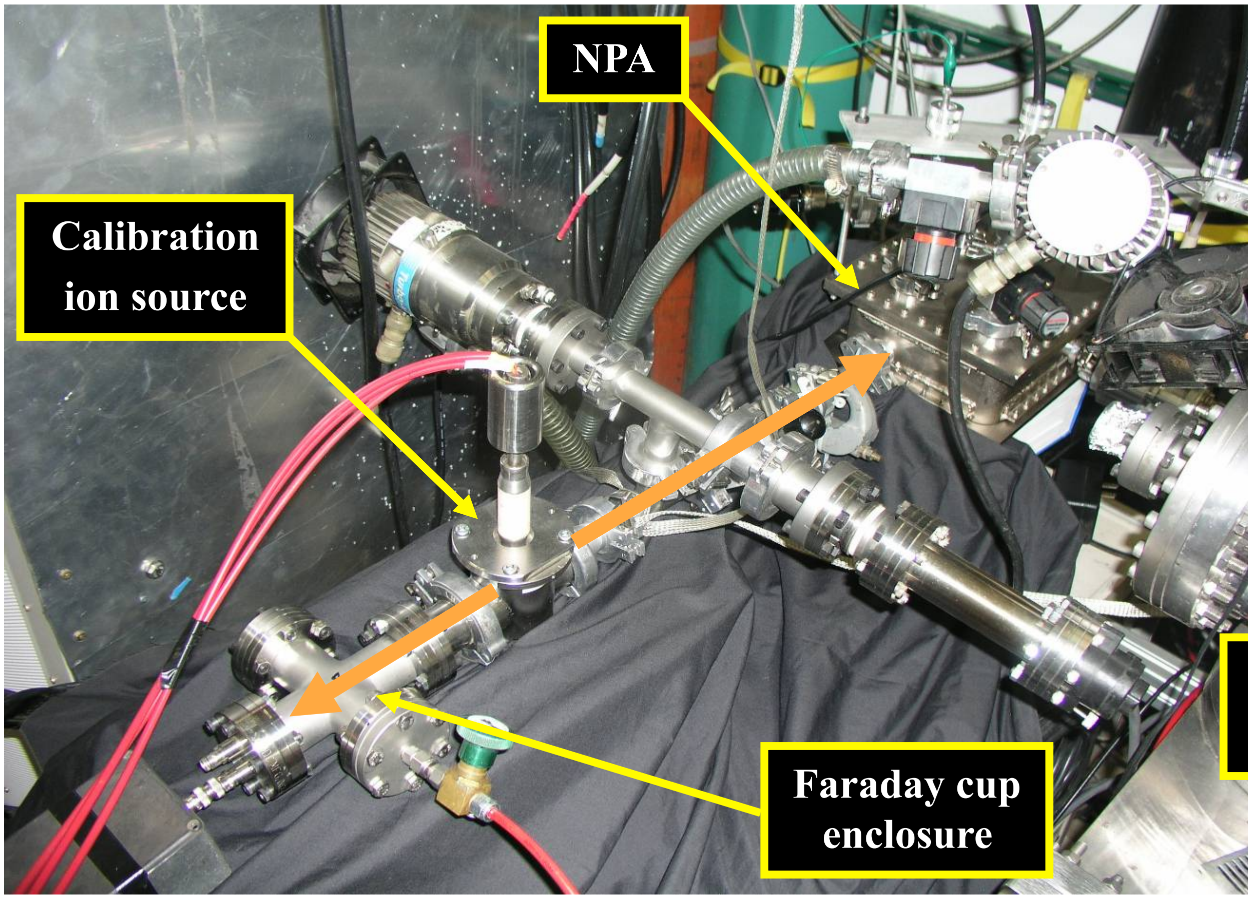
Electrostatic NPAs:
Trajectories depend on ion **energy per unit charge** only

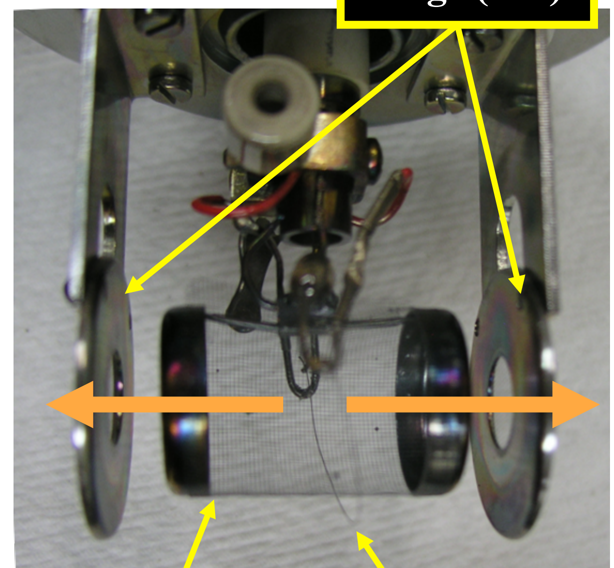


An electrostatic neutral particle analyzer (NPA) was engineered with modularity in mind



The NPA was calibrated below 30 keV with a filament-based ion source





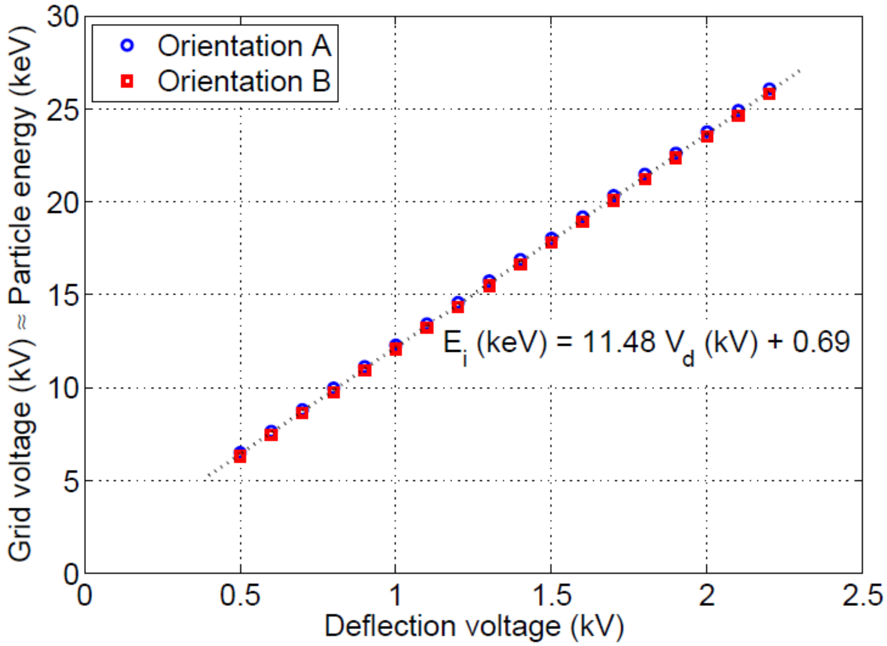
Calibration ion source

(borrowed from the Madison Symmetric Torus group)

The NPA was calibrated below 30 keV with a filament-based ion source

Helium-4 calibration

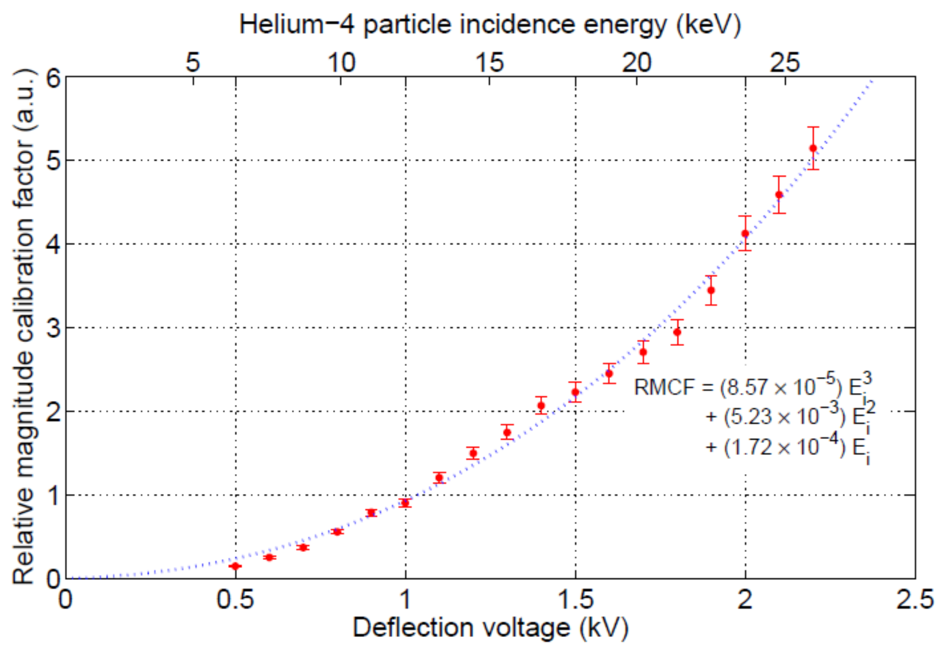
Energy calibration



$\Delta E/E \approx$ 2-4% in this range

$E_{max} \approx$ 170 keV

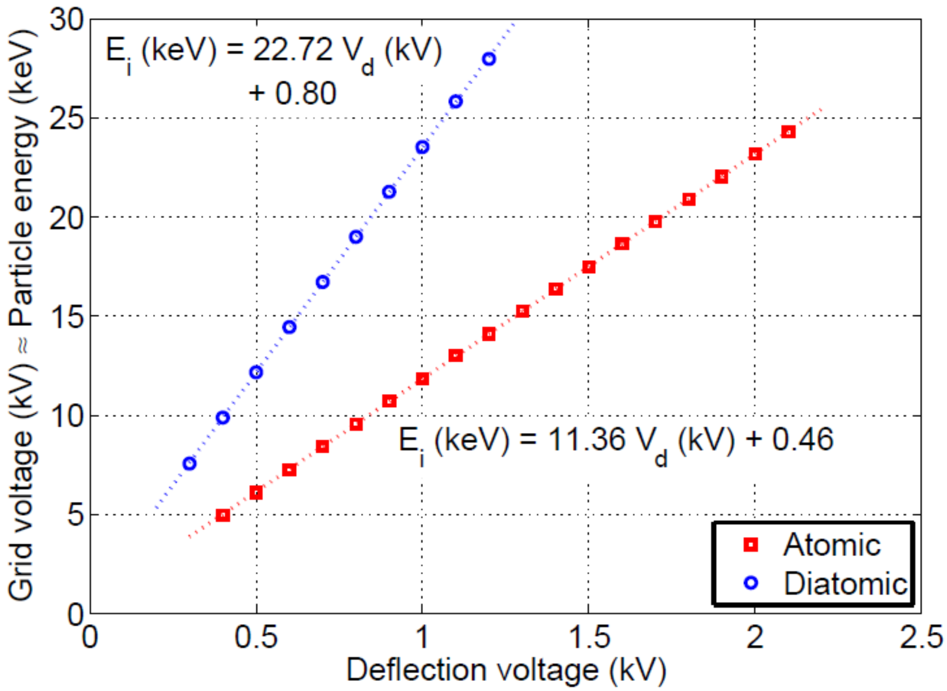
Relative magnitude calibration



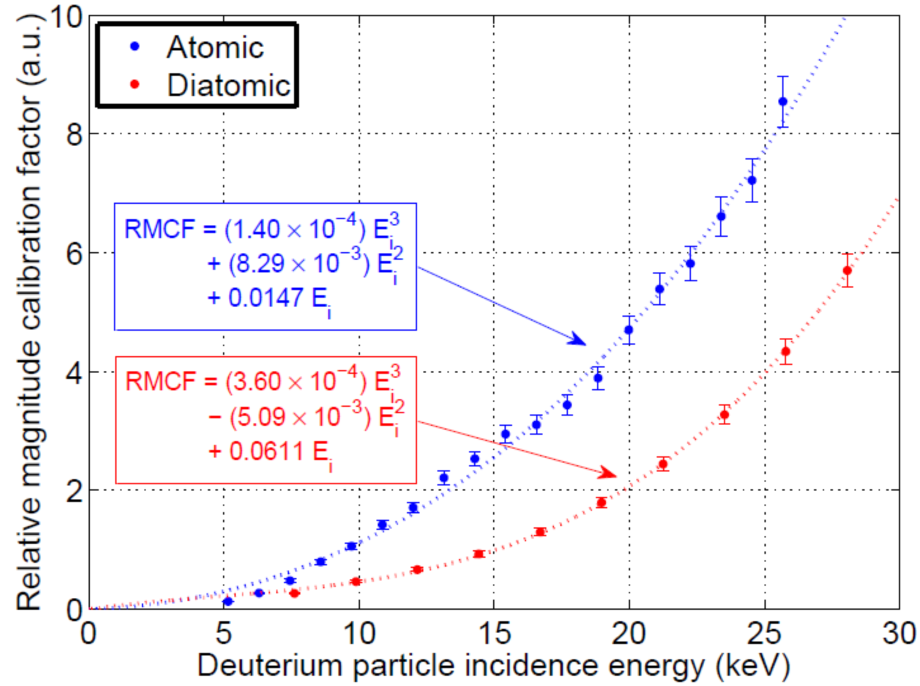
The NPA was calibrated below 30 keV with a filament-based ion source

Deuterium calibration

Energy calibration



Relative magnitude calibration

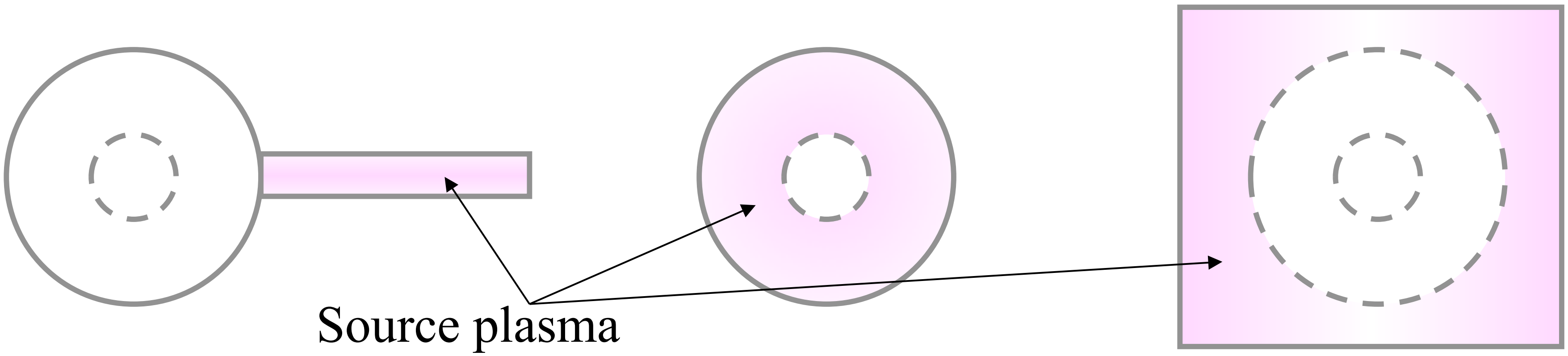


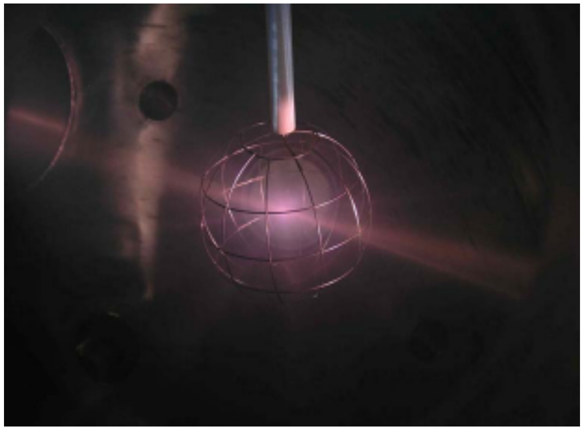
Experiments have been performed at cathode voltages up to 60 kV for three IEC source-plasma configurations

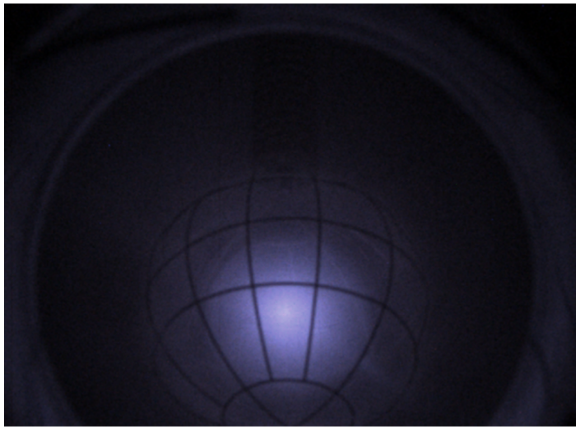
External ion source (HELIOS)

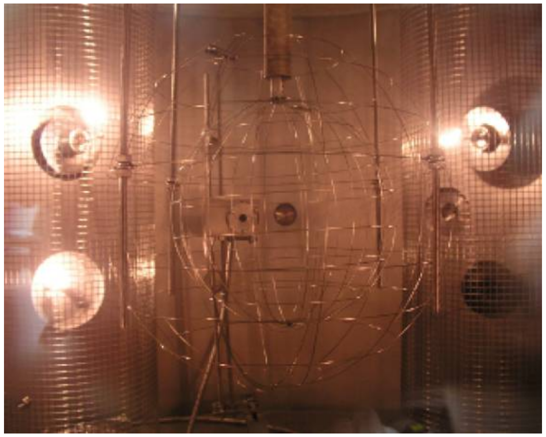
Glow discharge (HELIOS)

Filament-assisted (HOMER)



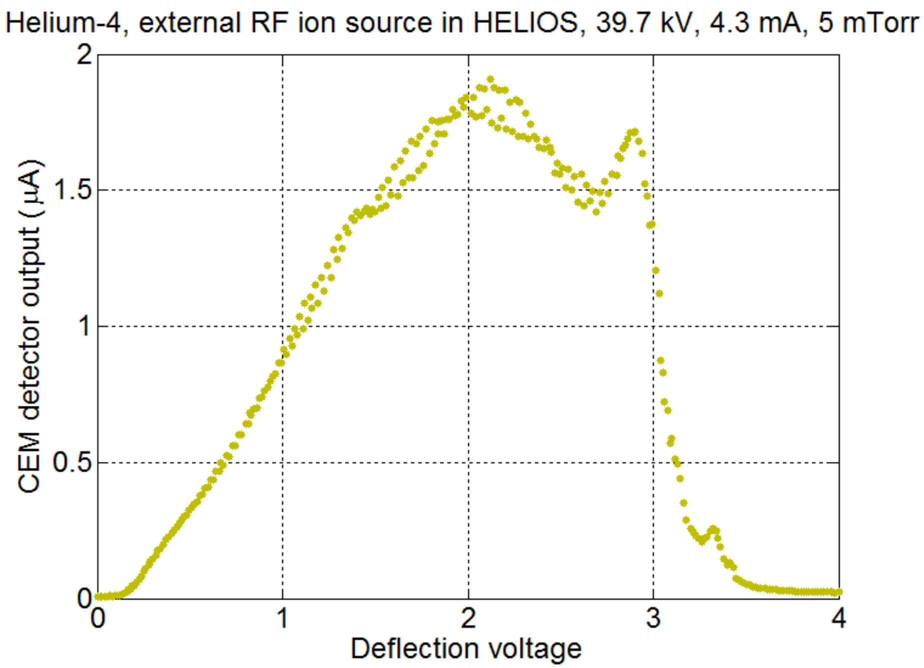


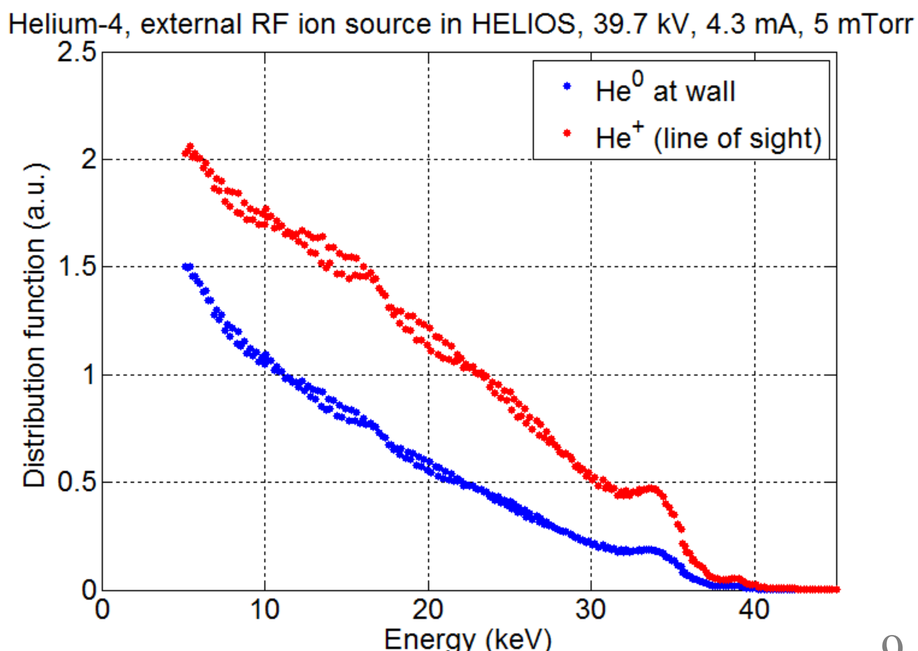




For helium, NPA data yields the energy distribution for fast neutrals (at the wall) and fast ions (line-averaged)

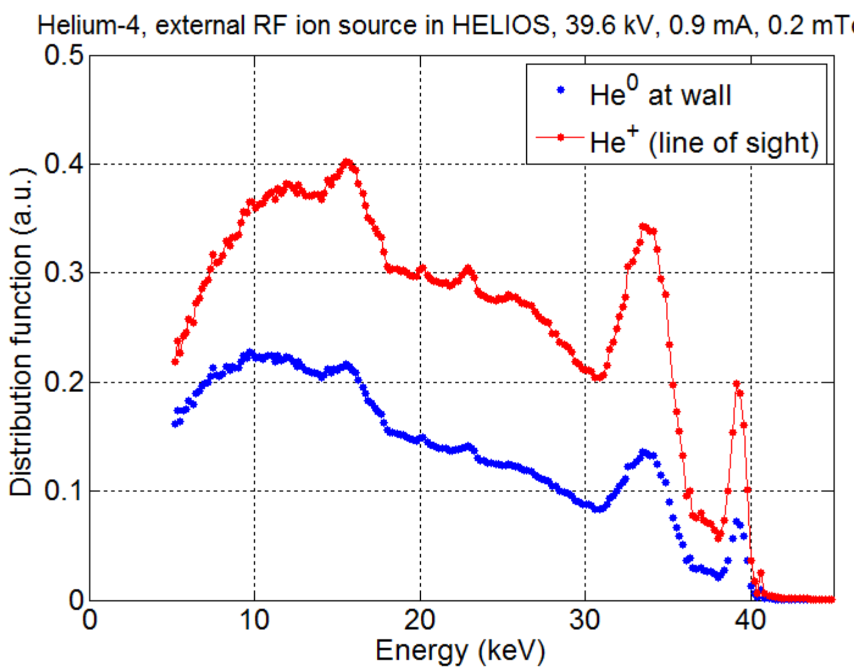
- The detector output, after calibration, yields the energy distribution of fast He^0 neutrals at the wall, also the spectrum for the parent ions.
- Since electron capture by He^+ is expected to be the dominant fast-neutral production mechanism, the cross section can be used to calculate a line-of-sight-averaged energy distribution for fast He^+ ions.



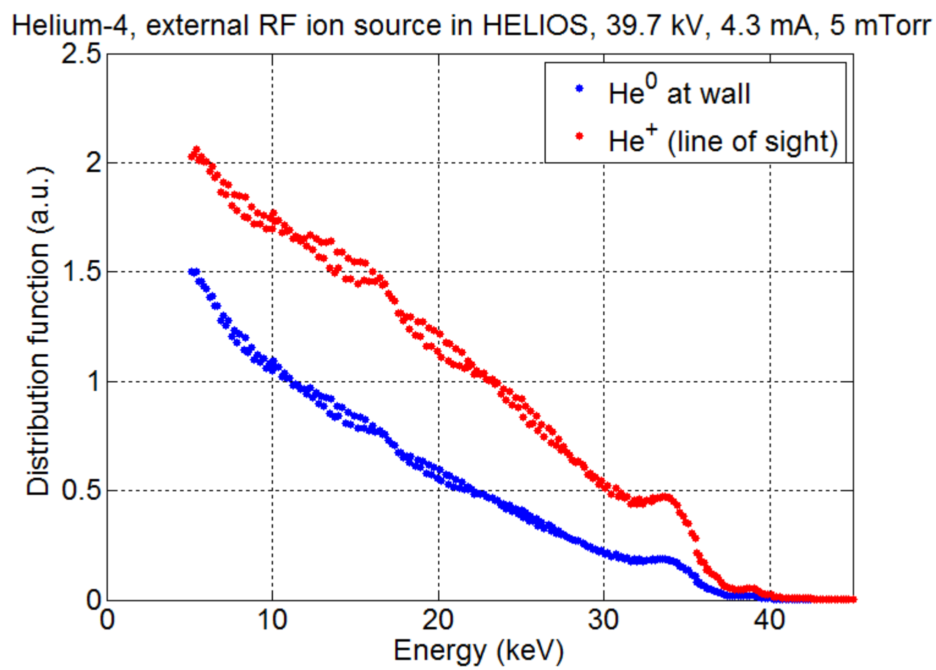


For the external-ion-source mode, the He energy spectra are significantly harder at a low background pressure

External ion source (0.2 mTorr = 27 mPa)

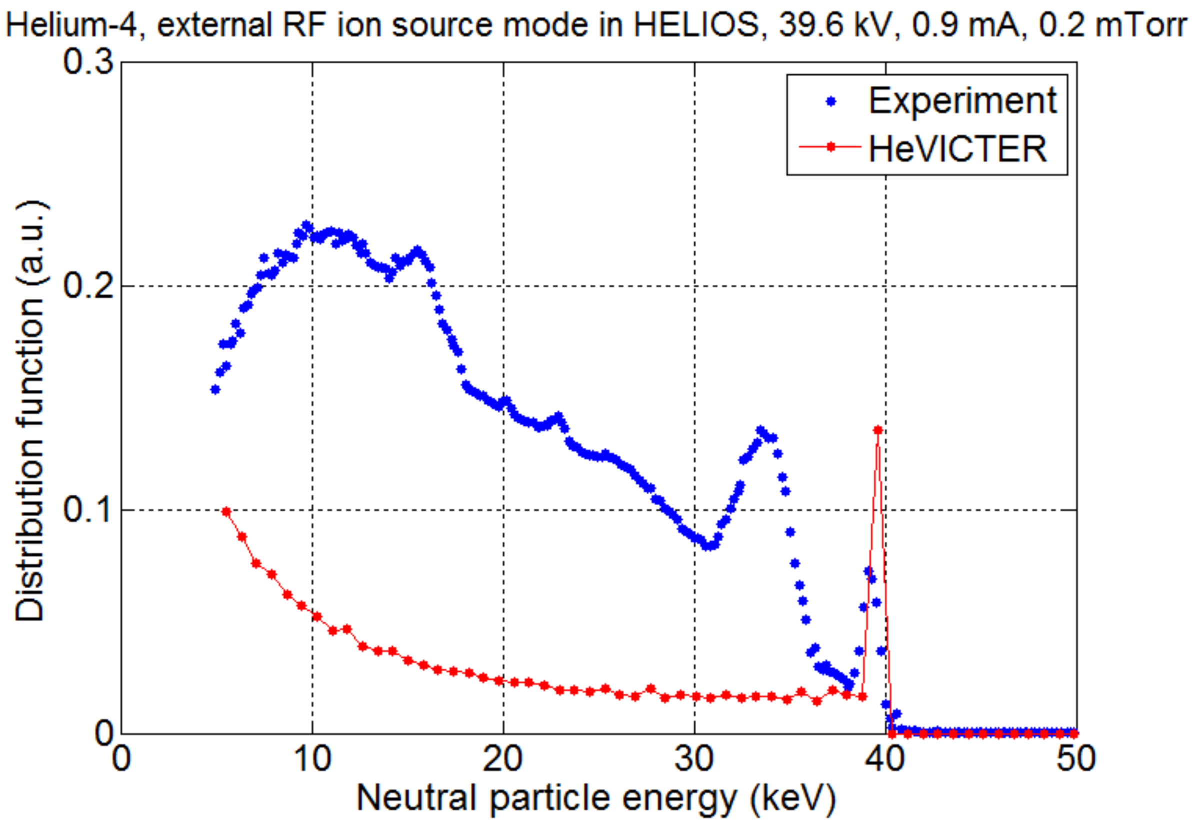


External ion source (5 mTorr = 667 mPa)



- First measurements of energy spectra in the external-ion-source mode in HELIOS.
- Confirmation of higher average energy is important for low-pressure operation for increased ^3He-^3He fusion rates.

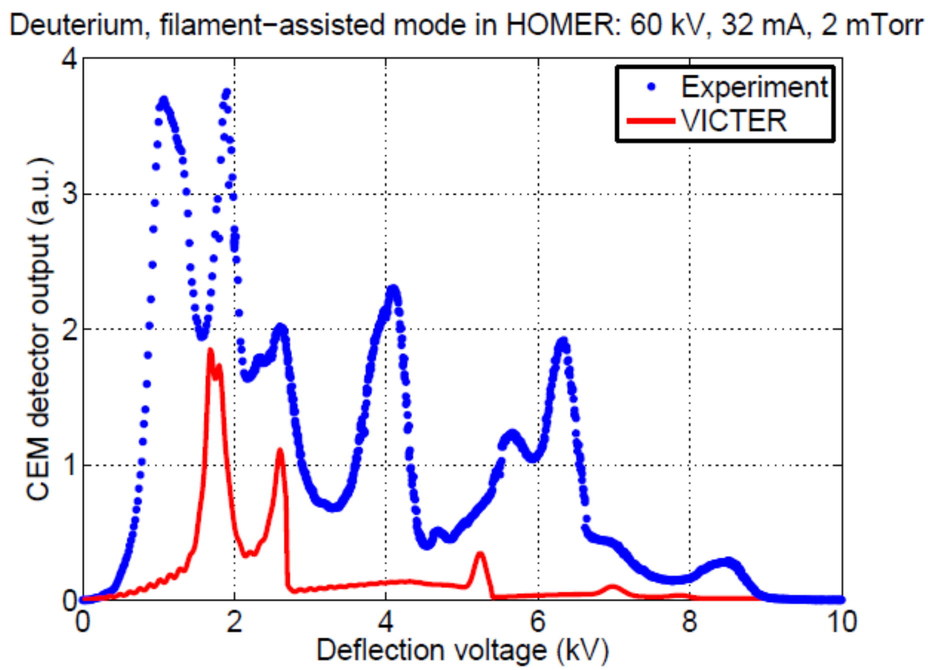
The HeVICTER code does not fully capture the details of the neutral energy spectra



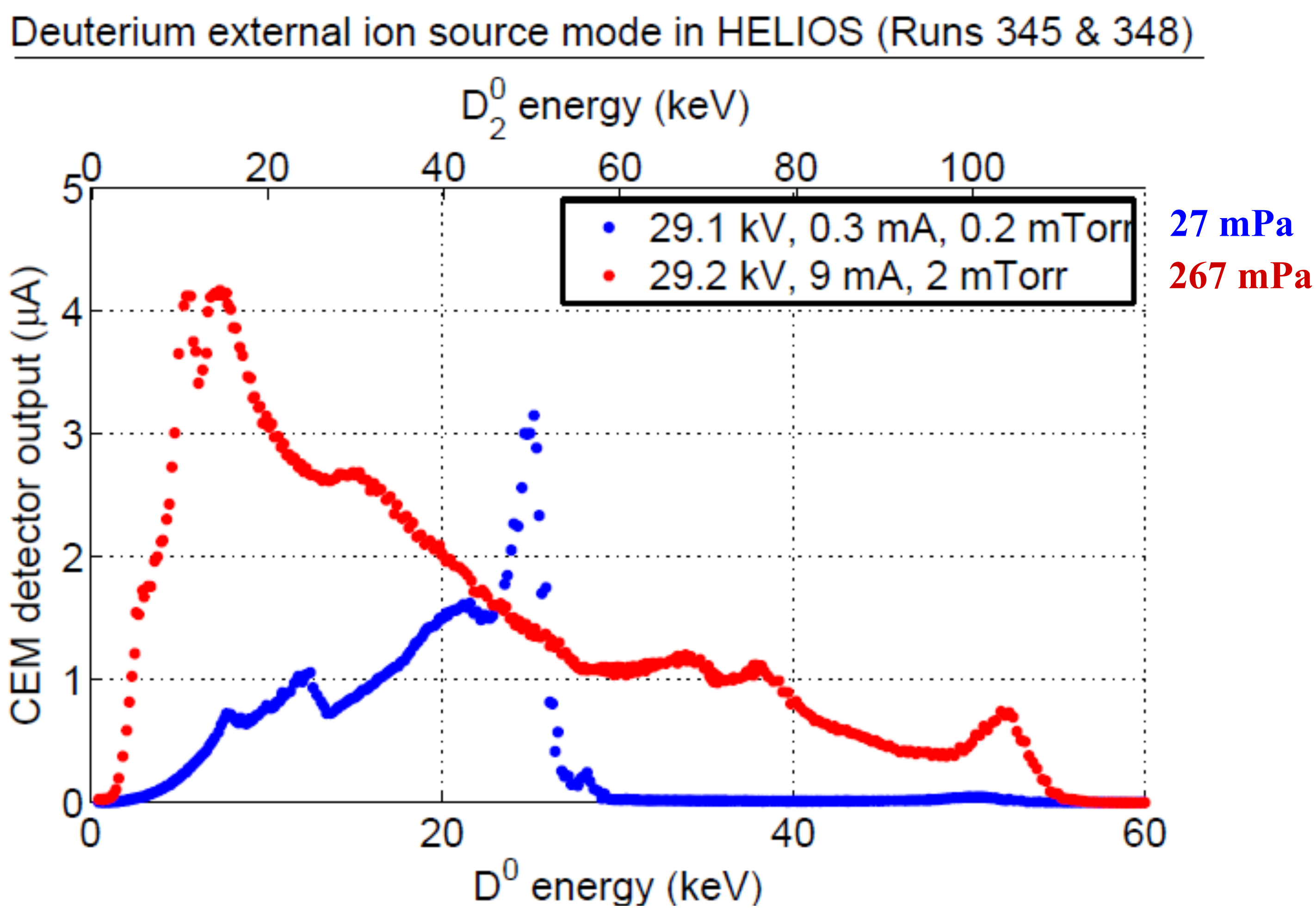
- Code predictions need to be reconciled with experimental data. Some electron physics and elastic scattering events are still missing. The NPA provides useful guidance for improved modeling.

The NPA was designed for ^{4}He experiments, but was also calibrated and used for deuterium experiments

- Both atomic (D^0) and diatomic (D_2^0) neutrals are generally transmitted from the stripping foil as atomic ions (D^+), so the NPA cannot distinguish between incident D^0 at a given energy and incident D_2^0 at roughly twice that energy.
- Deuterium data cannot at present be used to obtain neutral energy distributions. Also, there is no dominant mechanism for fast-neutral production, so it would not be possible to obtain ion energy spectra.
- The detector output as a function of deflection voltage can still be used to test predictions by numerical codes.



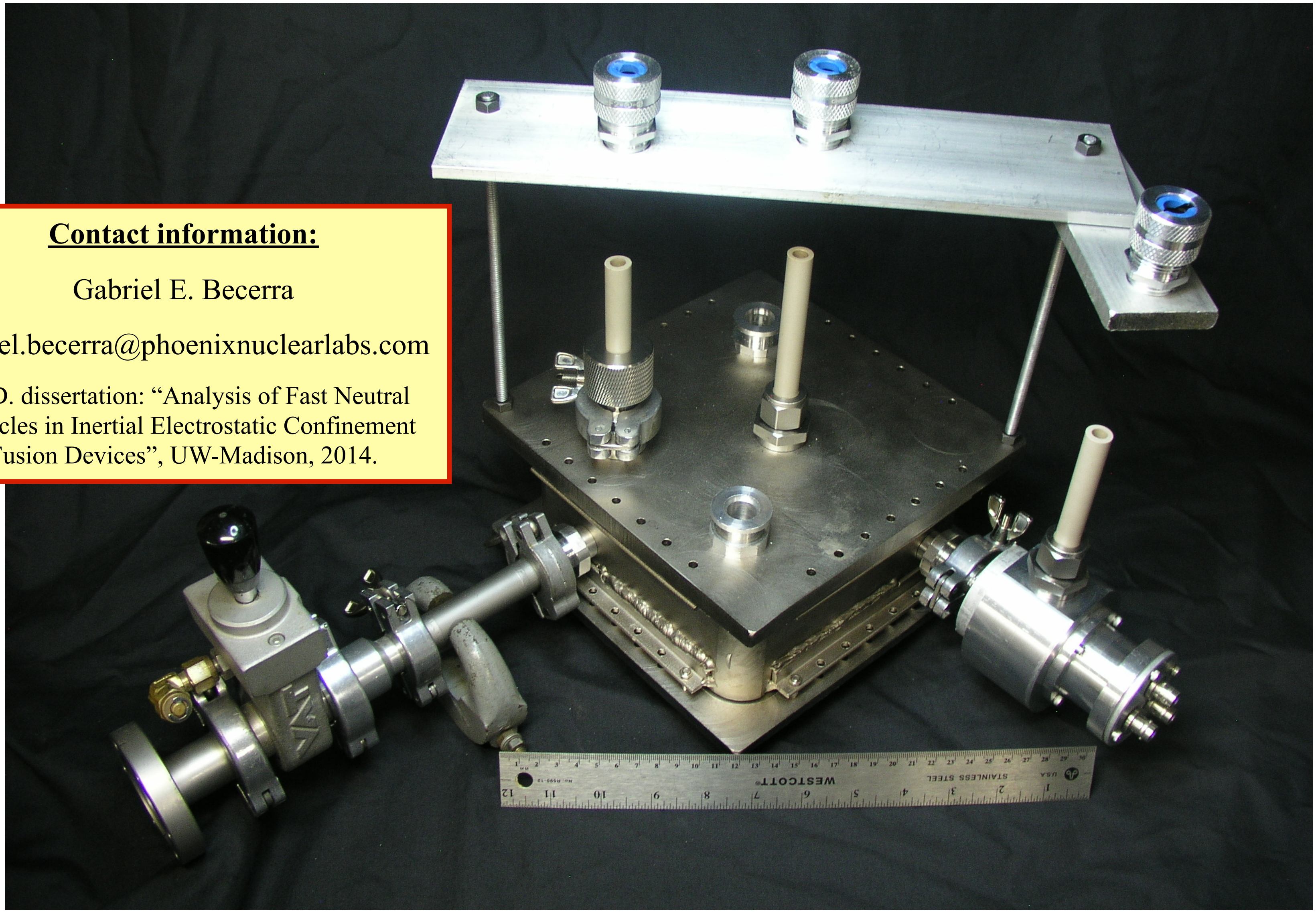
Deuterium results highlight the role of negative ions in fast-neutral formation at higher pressures



Summary and Conclusions

- The development of a neutral particle analyzer (NPA) provides a new way to study IEC physics, with superior counting statistics than fusion-product-based techniques, while also allowing for experiments at lower voltages and without fusion fuel.
- The NPA yields neutral and ion energy distributions for helium. It works as designed, with good energy resolution ($\Delta E/E \sim$ 2-4%), and can cover energies up to ~170 keV.
- This work opens up the possibility of extensive parametric studies in short times, which will be used for optimization of IEC devices for increased fusion rates.
- The energy spectra in the external-ion-source configuration have been confirmed to be significantly harder at low background pressure, which is crucial for the prospects of this mode for ^{3}He-^{3}He experiments.
- Predictions by the UW IEC numerical codes yield only limited qualitative agreement with the experimental results. The NPA provides a new tool for benchmarking the codes.

Questions?



Contact information:

Gabriel E. Becerra

gabriel.becerra@phoenixnuclearlabs.com

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