Astrochemistry in the Laboratory

Ash Bista (RIT)
Columbia Nevis Labs REU Program, Summer 2023
Savin Group

Research Group

Dr. Daniel Wolf Savin

Dr. Dmitry Ivanov

Star Formation

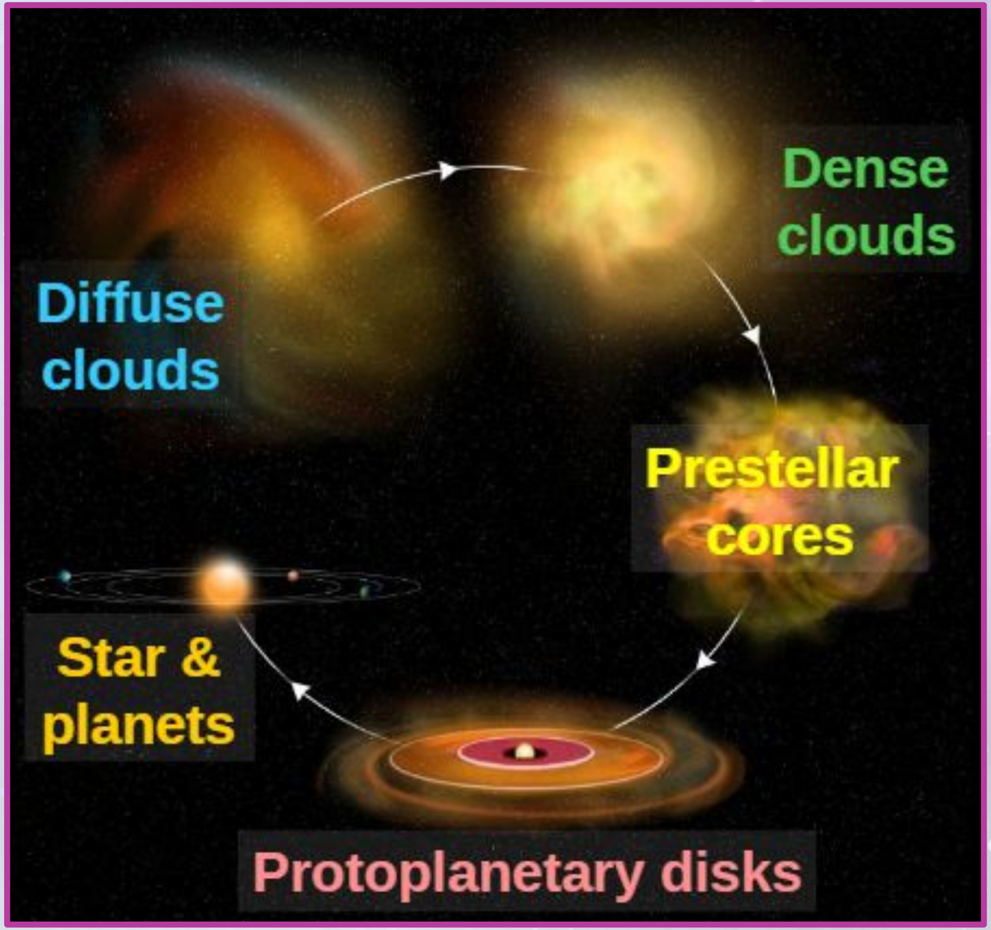


Figure Credit: Bill Saxton, NRAO/AUI/NSF

Stellar Evolution

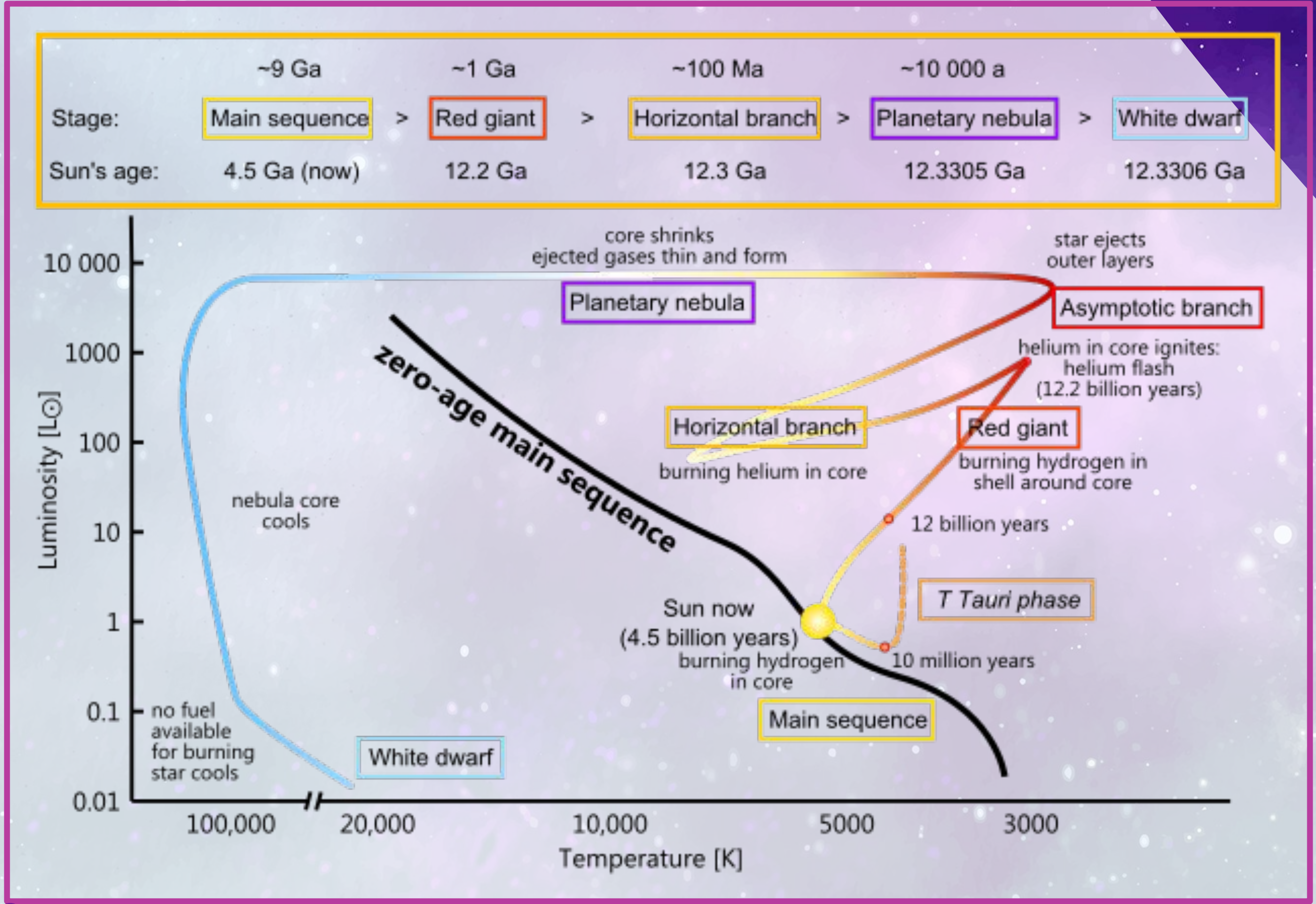


Figure Credit:
NASA/CXC/SAO

Tracing Stellar Evolution Using Chemistry

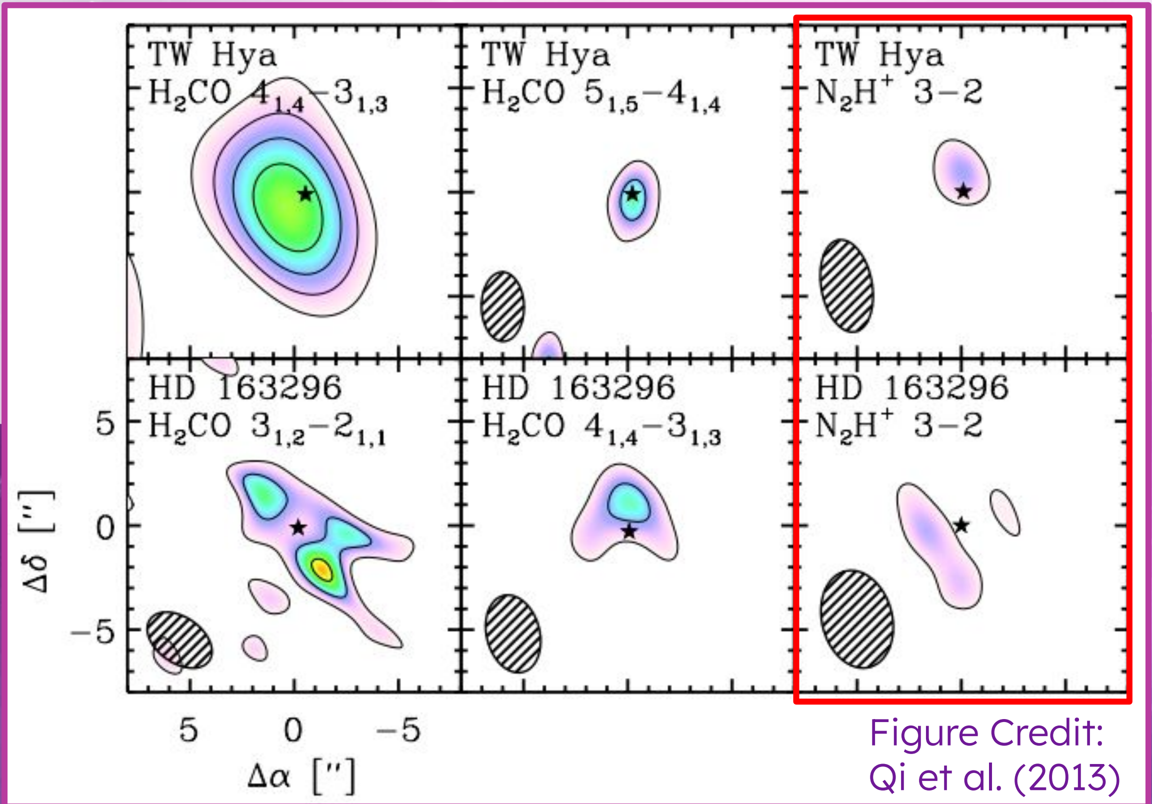


Figure Credit:
Qi et al. (2013)

Protoplanetary Disk

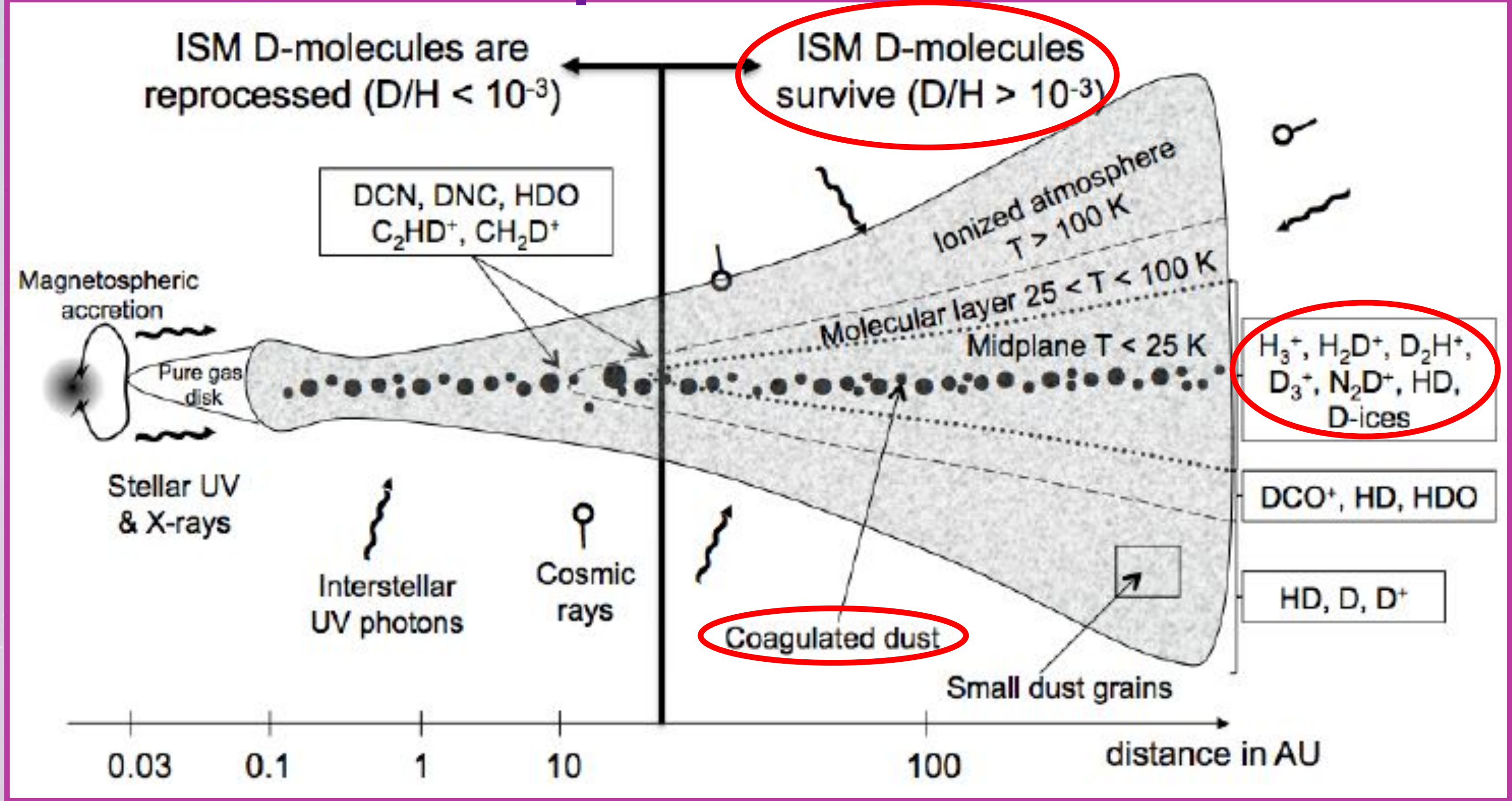


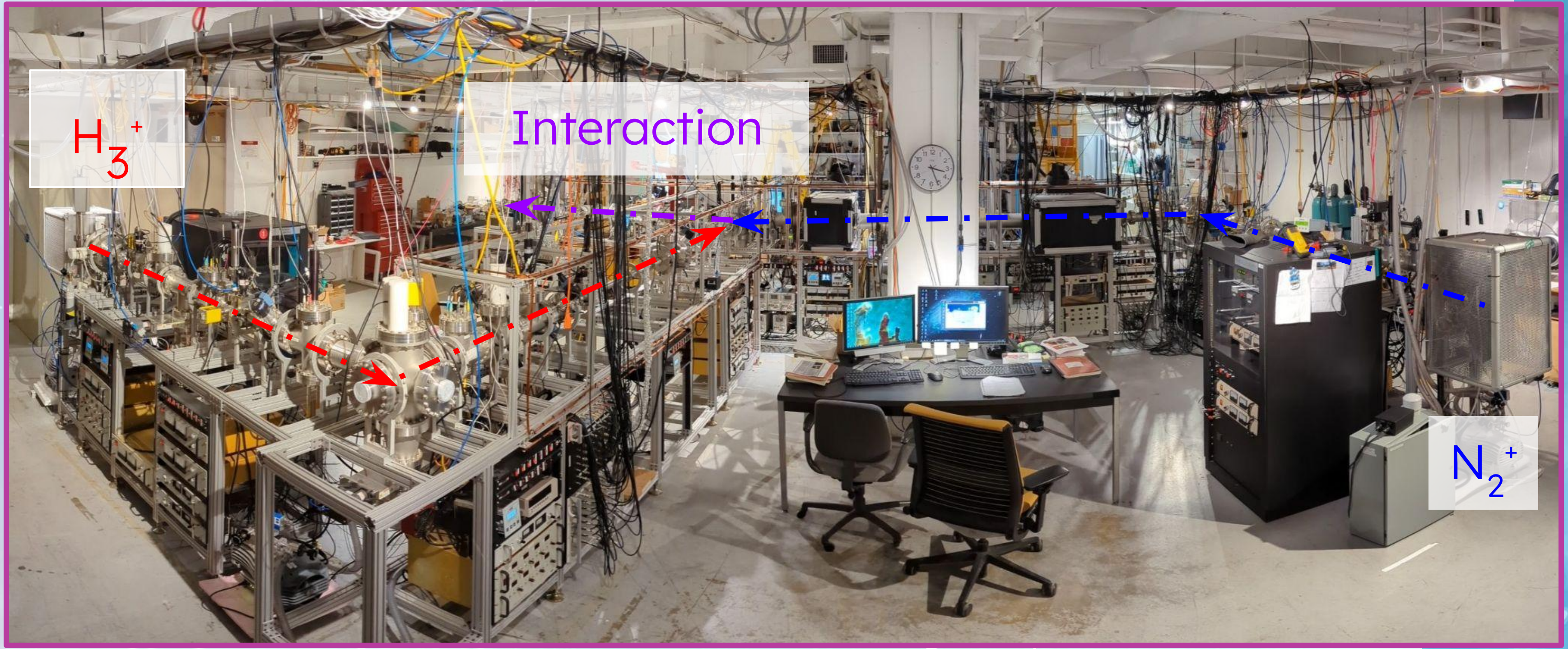
Figure Credit: Ceccarelli et al. (2014)

Public rate coefficients scatter by a factor of 2

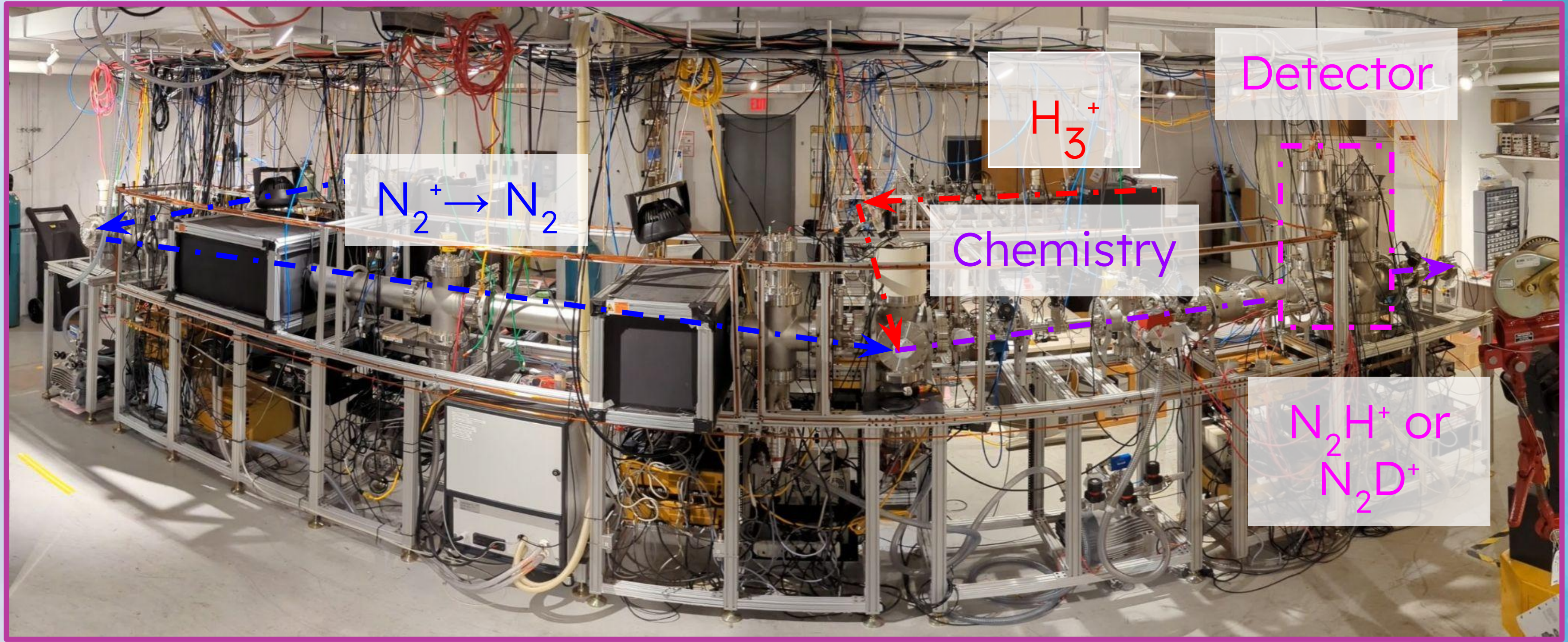
Formation of Ions

1) $N_2 + H_3^+ \rightarrow N_2H^+ + H_2$
2) $N_2 + H_2D^+ \rightarrow N_2H^+ + HD$
3) $N_2 + D_2H^+ \rightarrow N_2H^+ + D_2$
4) $N_2 + D_3^+ \rightarrow N_2D^+ + D_2$
5) $N_2 + D_2H^+ \rightarrow N_2D^+ + HD$
6) $N_2 + H_2D^+ \rightarrow N_2D^+ + H_2$

Dual-source ion-neutral merged-fast-beam apparatus



Dual-source ion-neutral merged-fast-beam apparatus



My Role

Experiment

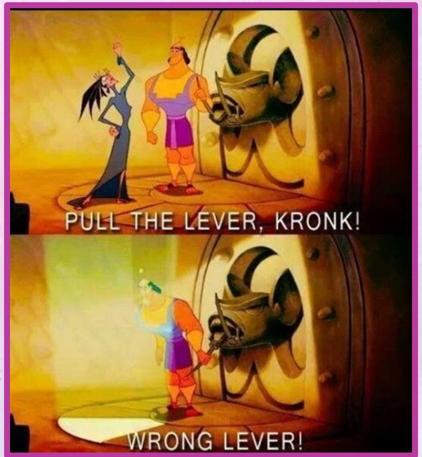
- Collect data
- Analyze data
- Recoat Filament

Hardware

- Inventory vacuum pumps
- Set up vacuum system
- Detect leak

Lab Safety

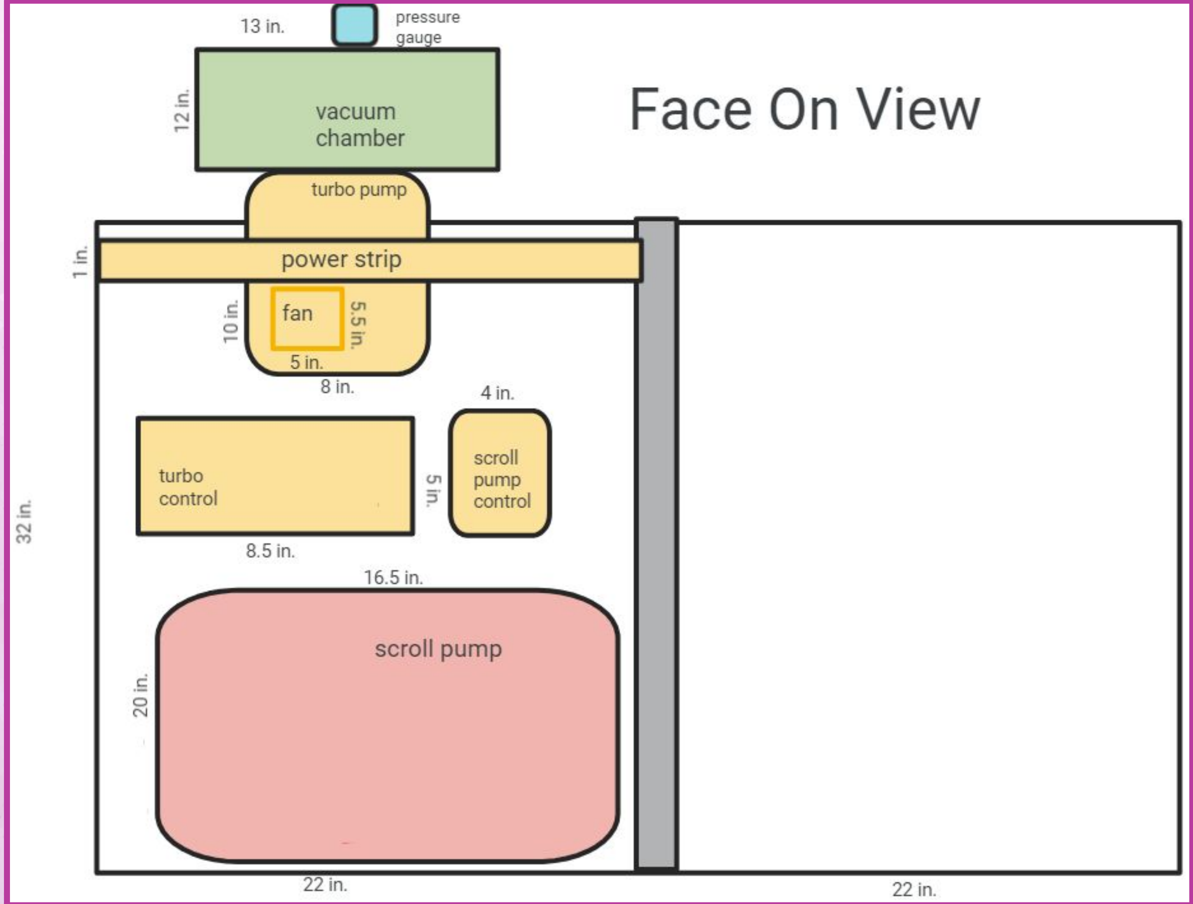
- Trace exhaust lines
- Report protocols for CO



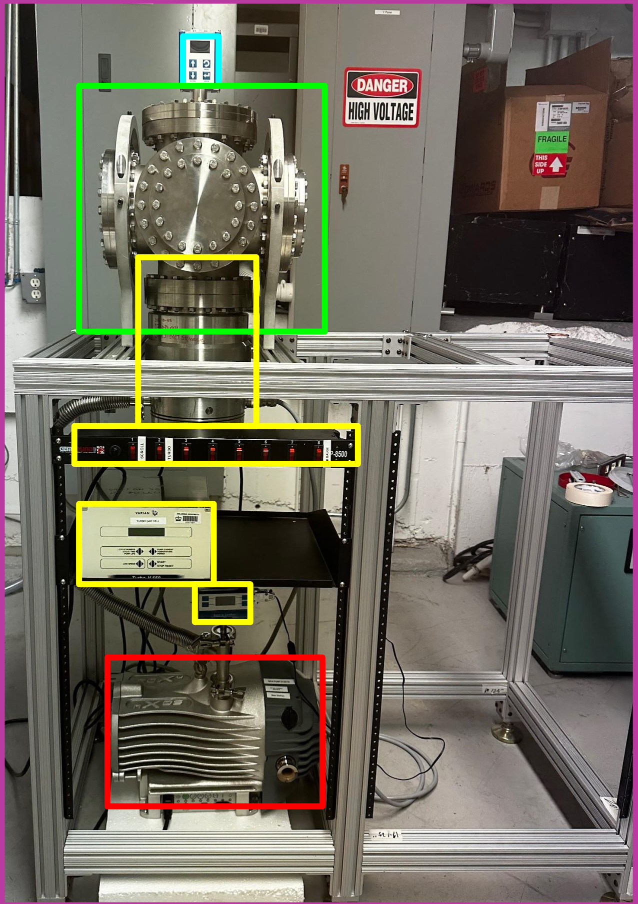
Turbomolecular Vacuum Pump List

Name	Model	Operating Hours	Current (A)	Pressure (torr)	Region
Neutral Source	HiPace 300	45135	0.62 +/- 0.03	2.00E-06	Hudson Line
2	HiPace 300	4497	0.37 +/- 0.04	2.00E-08	
3	HiPace 300	3199	0.40 +/- 0.02	3.00E-08	
4	TMU 521 P	87731	0.30 +/- 0.02	2.20E-08	
Dump	HiPace 350	2785	0.25	7.00E-08	
Merger/5	TC 110	397	0.40 +/- 0.05	5.00E-09	Interaction/Detection
Interaction/6	HiPace 300	2797	0.40 +/- 0.04	1.00E-08	
Final Analyzer/7	TV 551	51555	0.8	1.00E-08	
Ion Source	HiPace 300	14694	0.43	7.00E-07	Broadway Line
A	HiPace 300	32768	0.46 +/- 0.02	7.42E-06	
B	HiPace 300	32768	0.18 +/- 0.03	2.00E-08	
C	HiPace 300	2796	0.40 +/- 0.05	1.50E-08	

Stand

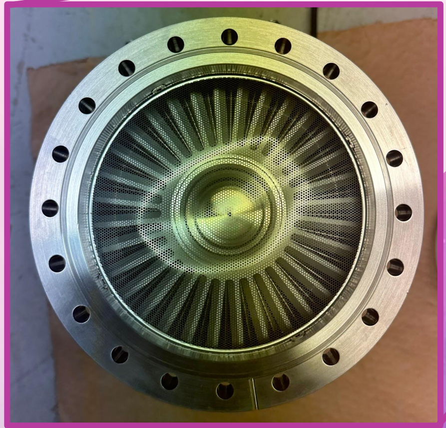


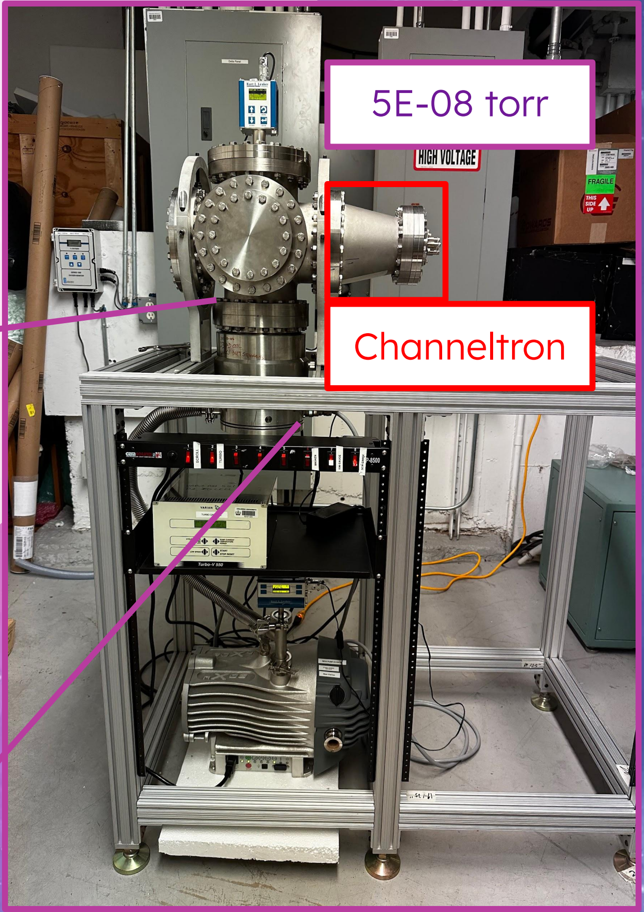
13 in.
pressure gauge
12 in.
vacuum chamber
Face On View
turbo pump
1 in.
power strip
10 in.
fan
5.5 in.
5 in.
8 in.
4 in.
turbo control
5 in.
scroll pump control
8.5 in.
32 in.
16.5 in.
scroll pump
20 in.
22 in.
22 in.



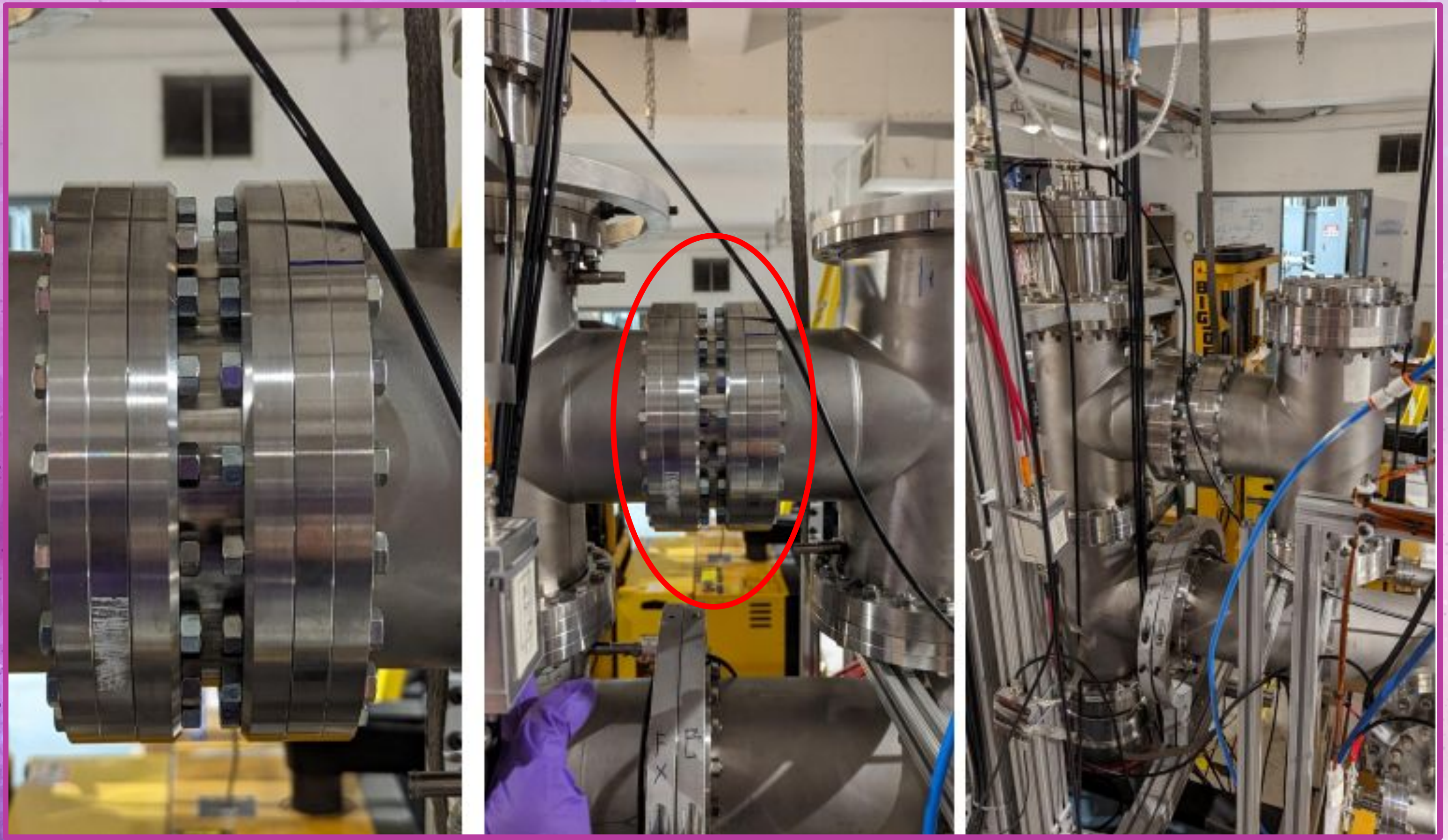
DANGER
HIGH VOLTAGE
FRAGILE
THIS SIDE UP

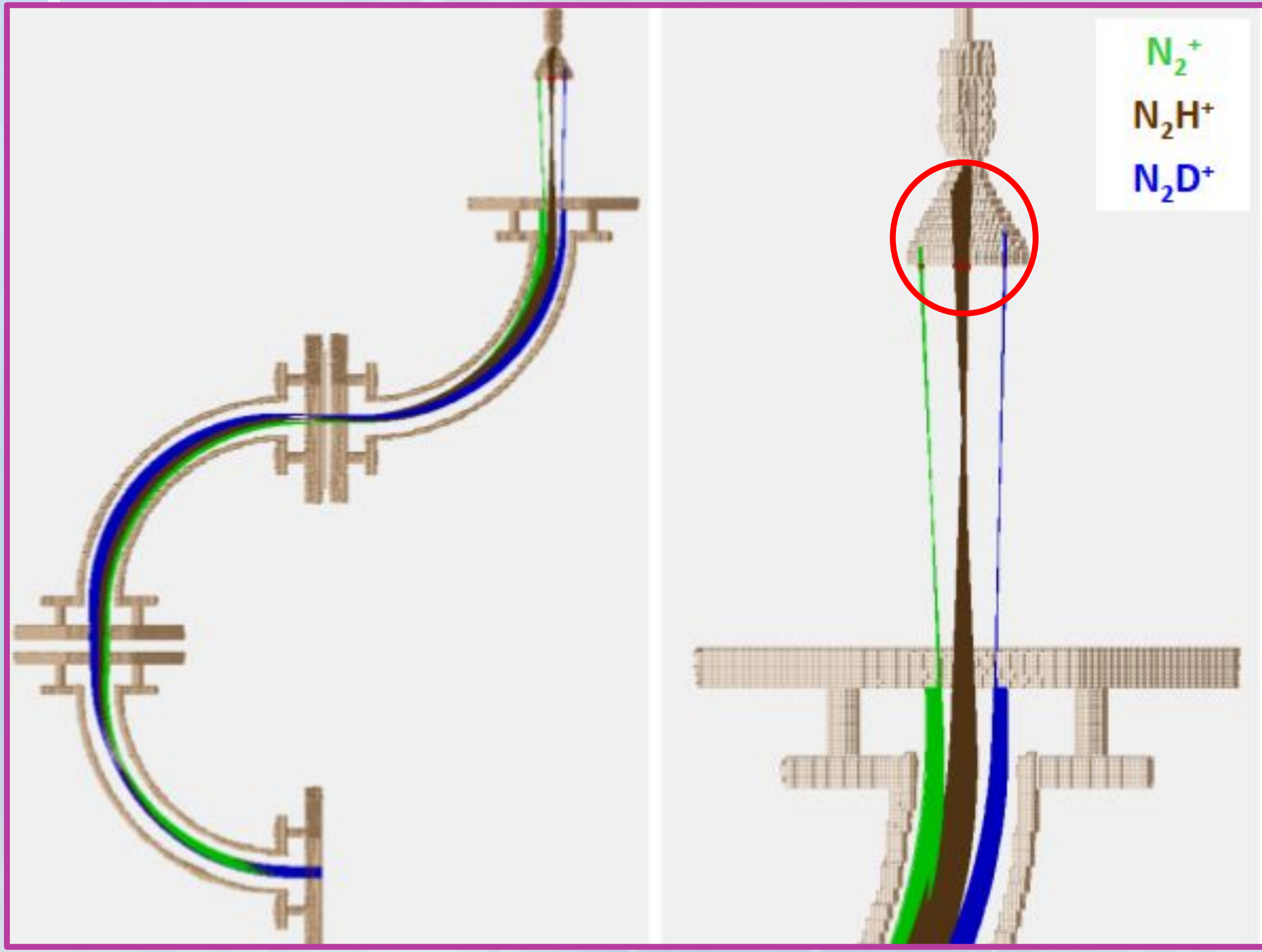
Stand





Extension





Ion	m, amu	E_K, keV
N_2^+	28.0129	20
N_2H^+	29.0213	20.71
N_2D^+	30.0270	21.43

Figure Credit:
Dmitry Ivanov

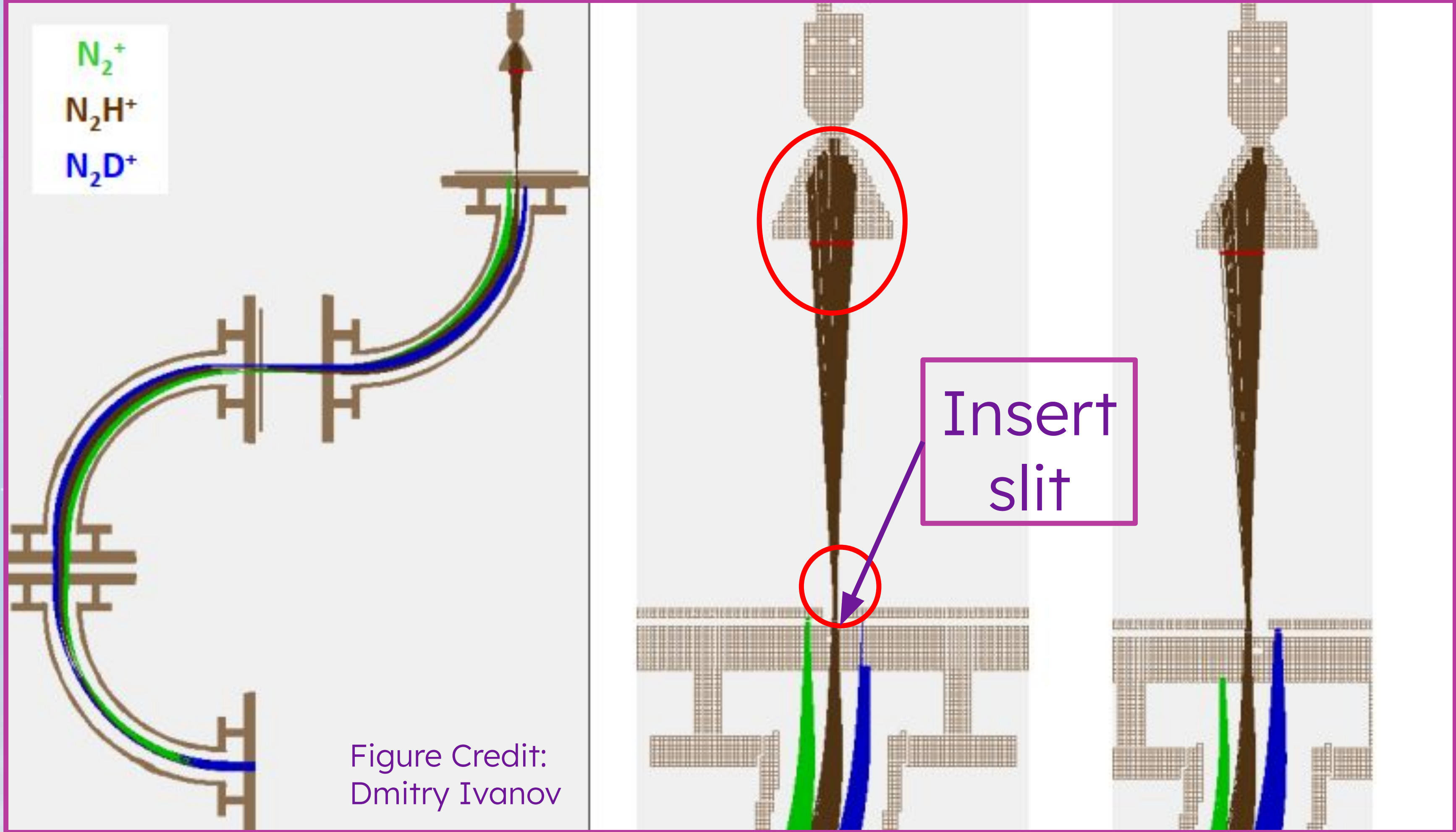


Figure Credit:
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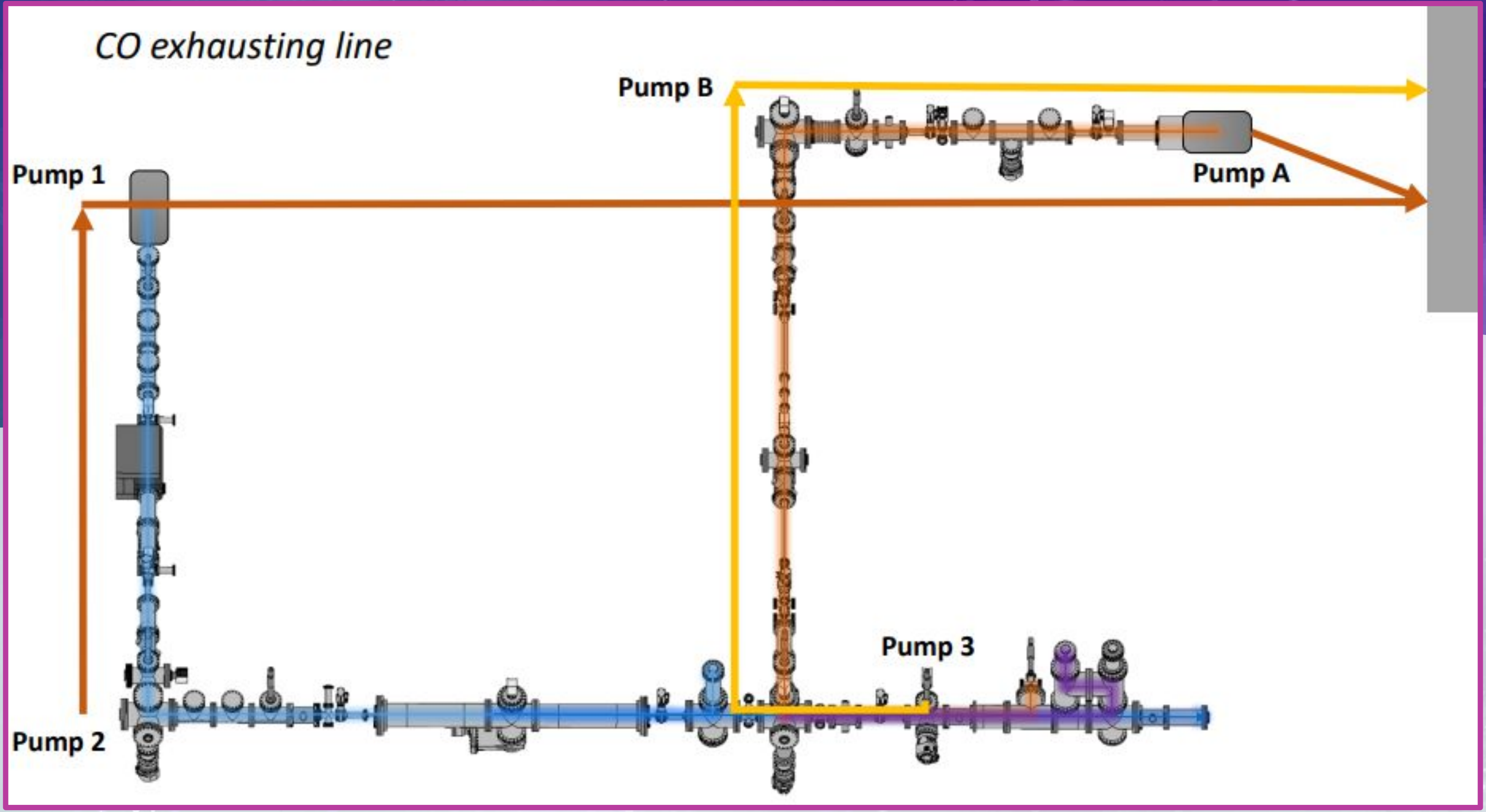
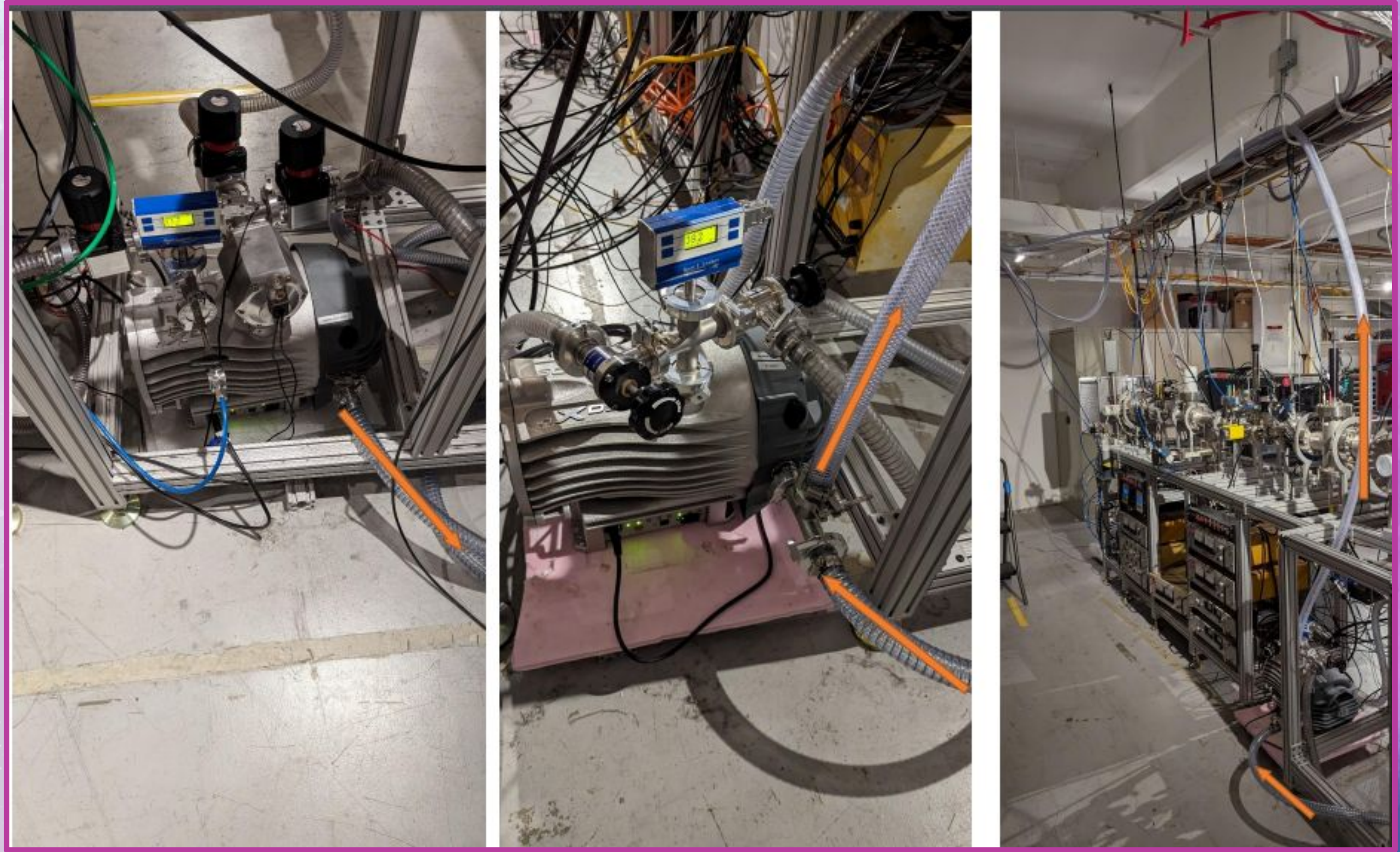
Leak Detection

- Check connections
- Pump out system & sections
  - Compare pressures
- Supply gas to system/sections
  - Check pressures over time
- Use leak detector liquid



Tracing Exhaust Lines

Tracing Exhaust Lines

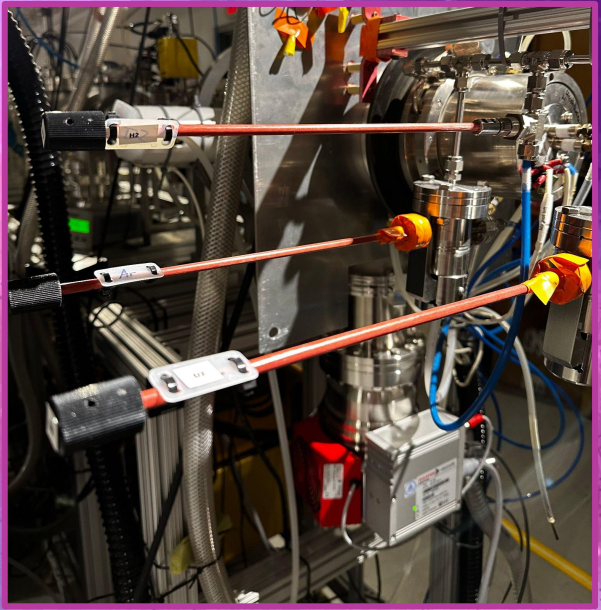


CO Safety

- Met with Columbia’s Environmental Health & Safety on 06/27/2023
- Requirements:
  - Detector
  - Gas Cabinet
  - Steel Lines
  - Flash Arrestors
  - Signs
  - Training

Experimental Steps

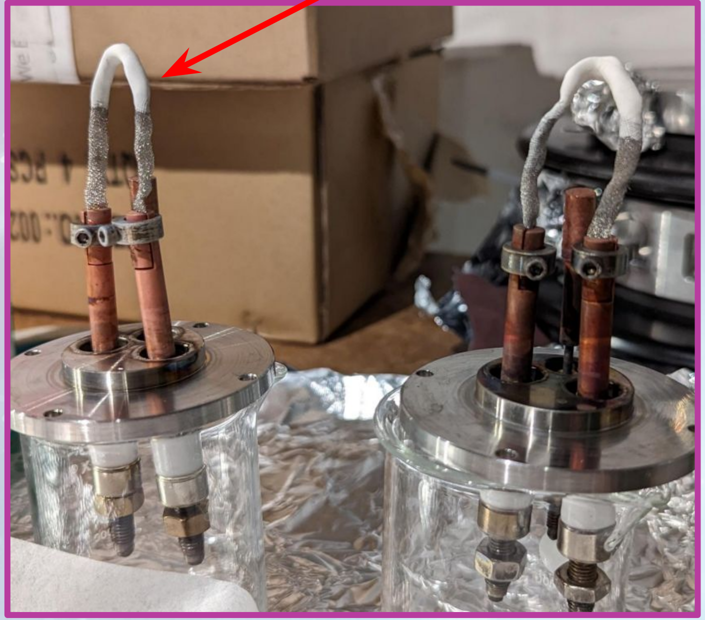
1) Cool System
2) Heat Filament
3) Refresh Gas
4) Enable & Optimize Ion Optics
5) Check Beam Profiles
6) Record Measurements



Recoating the Filaments

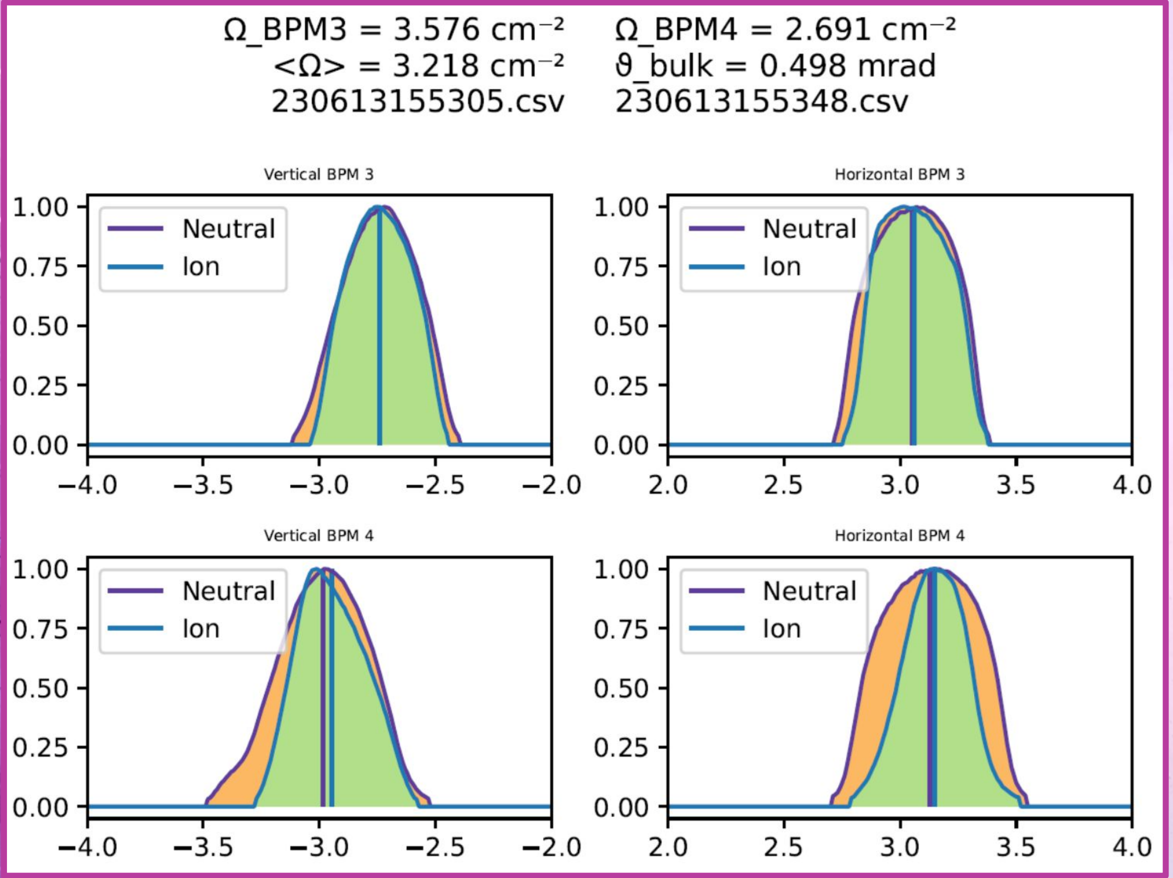
Before
(360 hours)

Ba-Sr-Ca



After

Beam Profiles



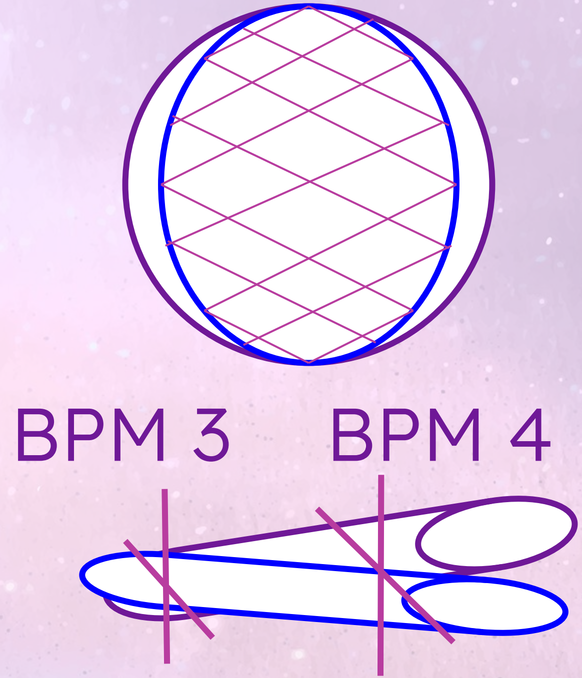


Figure Credit: Dmitry Ivanov

Equation/Measurements

Ion Beam: 5 keV
Neutral Beam: 23 keV

ICS * Relative Velocity
Avg. over Energy Spread

Signal Counts
→ 24 keV

Electron Charge
Squared

Velocities

$$\langle \sigma v_{\mathrm{r}} \rangle = \frac{S}{T_{\mathrm{a}} T_{\mathrm{g}} \eta} \frac{e^2}{I_{\mathrm{n}} I_{\mathrm{i}}} \frac{v_{\mathrm{n}} v_{\mathrm{i}}}{L \langle \Omega(z) \rangle}$$

Transmissions &
Detection Efficiency

Currents/
Intensities
(100s nA)

Interaction
Length
1.2 m

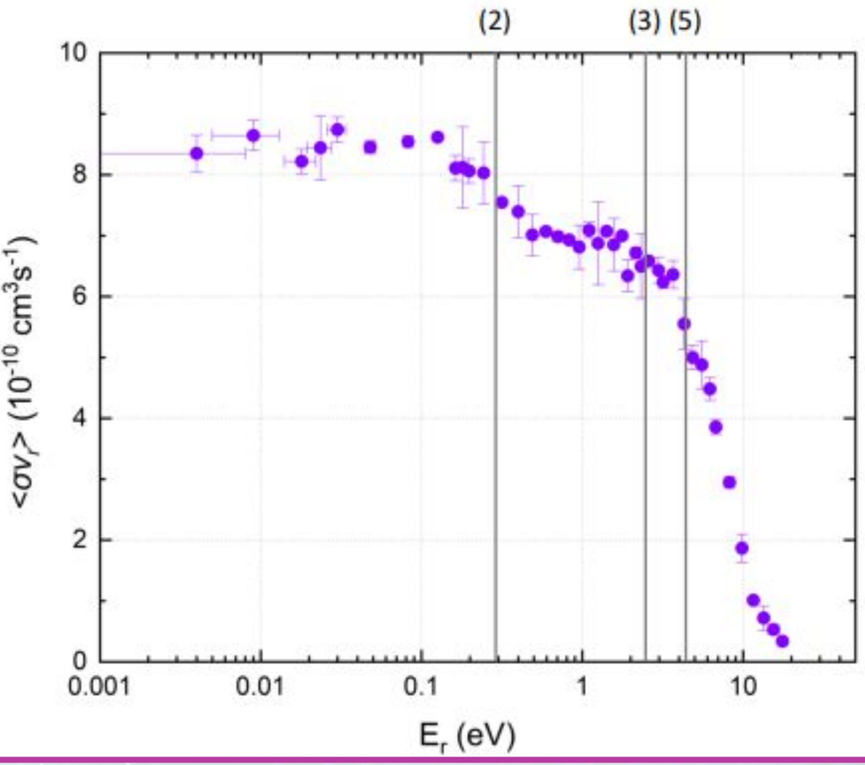
Avg. Overlap
Factor (cm^-2)
along propagation
axis z

Equation Credit: O’Connor et al. 2015a

How to Measure a Neutral Signal

1) Fast neutral beam
2) Hits target to produce electrons
3) Electrons are collected & measured
    a) Current signal (in nA)
4) Convert electron signal into a neutral current signal

Final Results



$N_2(v=0) + H_3^+ \rightarrow$		$-\Delta E$, eV
(1)	$N_2H^+ + H_2$	-0.74
(2)	**$N_2(v=1) + H_3^+$**	**0.29**
(3)	**$N_2H_2^+ + H$**	**2.42**
(4)	$N_2H^+ + H + H$	3.74
(5)	**$N_2 + H_2 + H^+$**	**4.38**
(6)	$N_2 + H_2^+ + H$	6.20
(7)	$N_2^+ + H_2 + H$	6.36
(8)	$N_2 + H + H + H^+$	8.85
(9)	$N + N + H + H + H^+$	18.61

Figure Credit:
Dmitry Ivanov

Thank You

Any questions?

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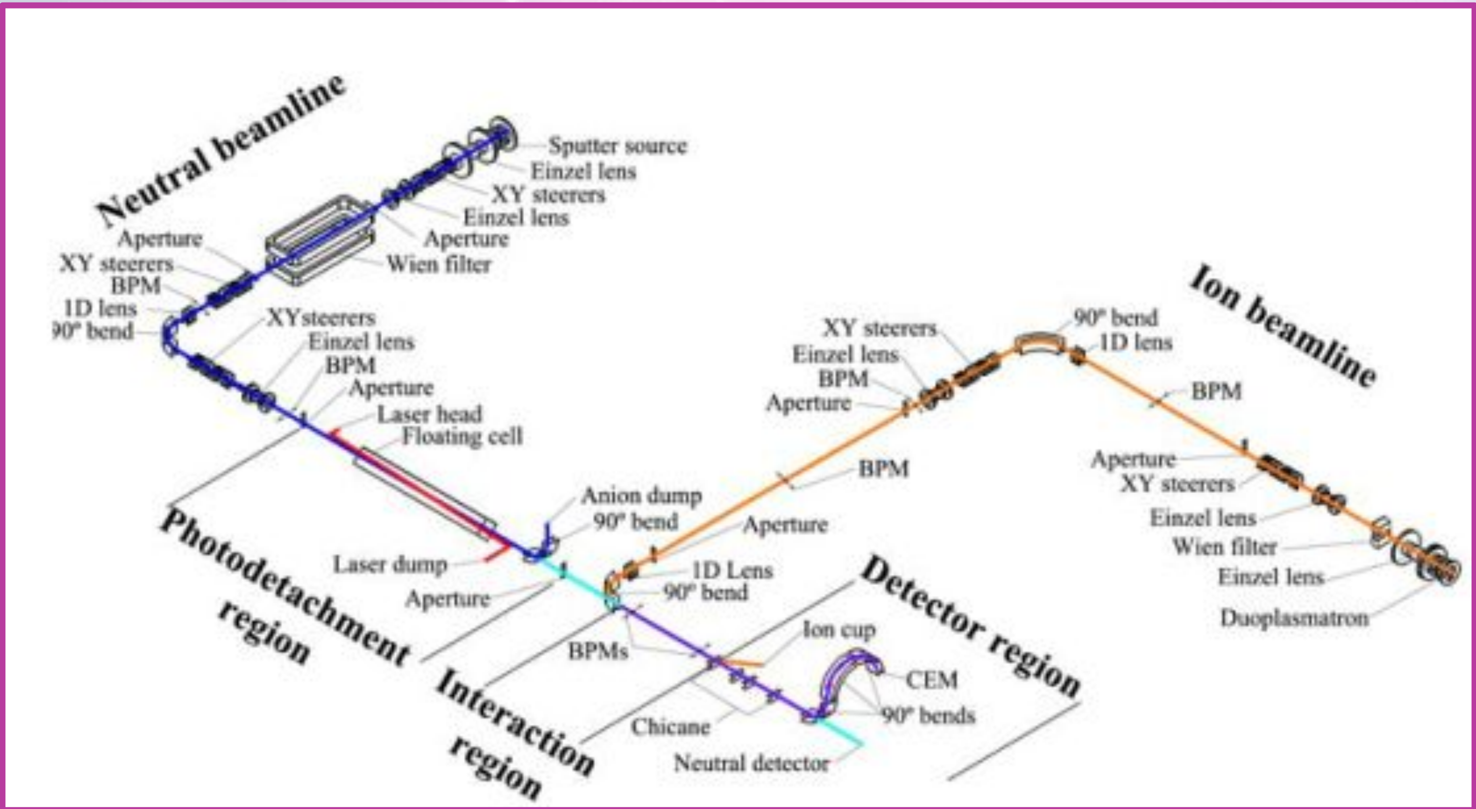
Dual-source ion-neutral merged-fast-beam apparatus



Relative Energy Equation

$$E_{\mathrm{r}} = \mu\left(\frac{E_{\mathrm{D}}}{m_{\mathrm{D}}} + \frac{E_{\mathrm{i}}}{m_{\mathrm{i}}} - 2\sqrt{\frac{E_{\mathrm{D}}E_{\mathrm{i}}}{m_{\mathrm{D}}m_{\mathrm{i}}}}\cos\theta\right)$$

```
# Floating Cell Voltage Equation:

def Uf(En,Ei,mn,mi): # defining function (Uf) and parameters: energy of neutrals (En) ; energy of ions (Ei) ; mass of neutral (mn) ; mass of ion (mi)
  Uf = Ei*(mn/mi)-En # derived from KE = 1/2 m v^2
  return Uf # in keV
```

```
[ ] # Print Uf Value: (Note: for En = 21 keV just subtract 1 eV)

En = 20 # energy of neutrals in keV
Ei = 4.9 # energy of ions in keV
mn = 28.0134 # mass of neutral in any units
mi = 6.0423053334 # mass of ion in same units as mn
z = Uf(En,Ei,mn,mi)
print(z)
```

```
2.7174319114987107
```

```
[ ] # Energy of Daughter Product Equation:

def E(En,Ei,Uf): # defining function (E) and parameters: energy of neutral (En) ; energy of ion (Ei) ; floating cell voltage (Uf)
  E = En + Uf + Ei/3
  return E # in keV
```

```
[ ] # Print E value: (Note: same E value for 20 keV and 21 keV)

En = 20 # energy of neutral in keV
Ei = 4.9 # energy of ion in keV
Uf = z # floating cell voltage in keV
print(E(En,Ei,Uf))
```

```
24.350765244832044
```

Neutral Signal Conversion

$$I_n = \frac{I_{ND}}{\gamma T_n}$$

Gamma Factor

$$\gamma = \frac{I(N_2)_{fin}}{I(N_2^+)_{up} - I(N_2^+)_{up}^{gas}} \cdot \frac{I(N_2^+)_{up}}{I(N_2^+)_{fin}}$$

1.81 +/- 0.01

Transmissions

$$T_n = \frac{I(N_2^+)_{fin}}{I(N_2^+)_{int}}$$

1.00

Neutral

$$T_i = \frac{I(D_3^+)_{chicane}}{I(D_3^+)_{FCC}}$$

0.93

Ion

Preliminary Results