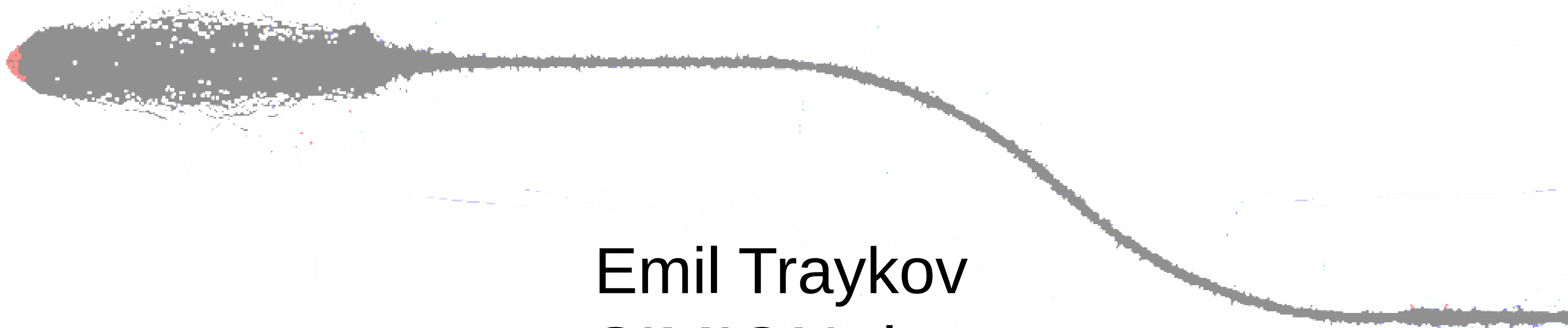
Ion-atom interactions in a gas jet

coupling of a gas catcher to a linear RFQ cooler

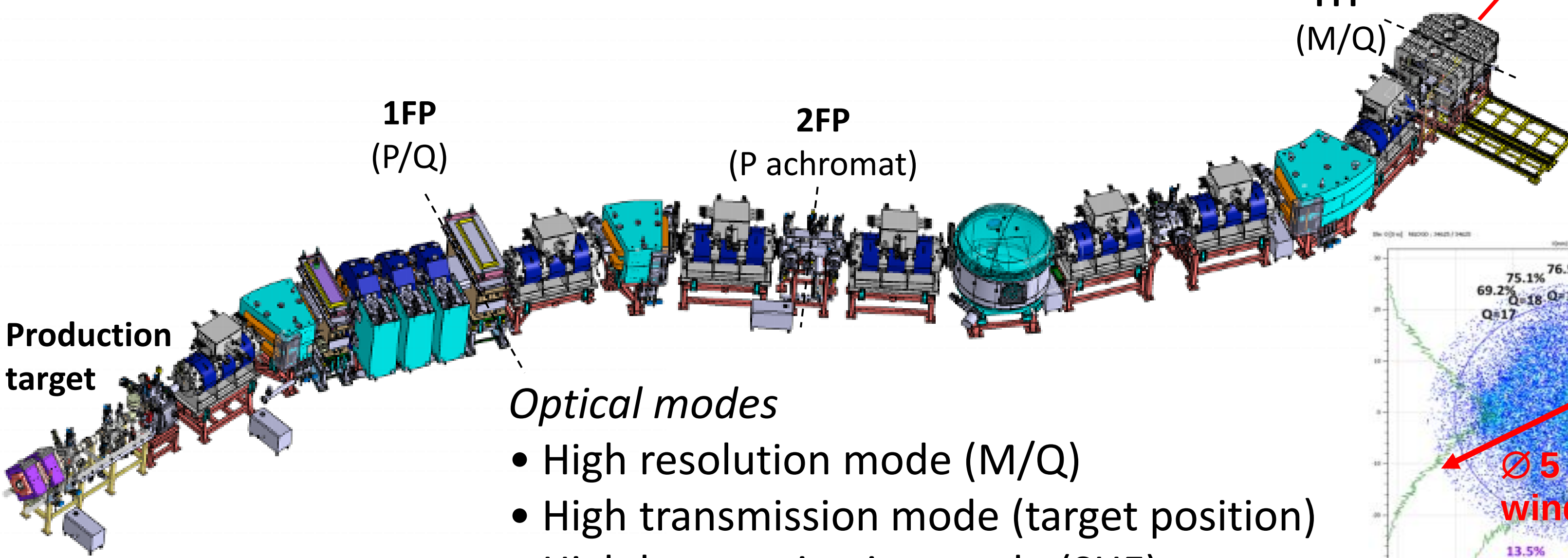


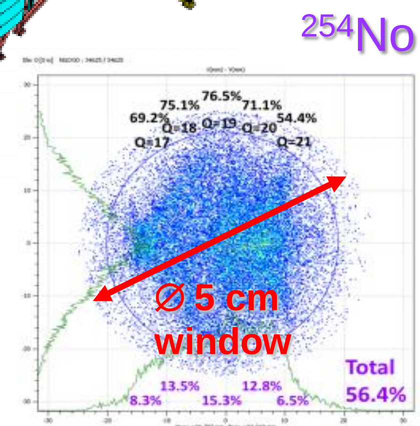
Emil Traykov

SIMION day

GANIL, 11/06/2015

S^3 spectrometer and the low energy beam line



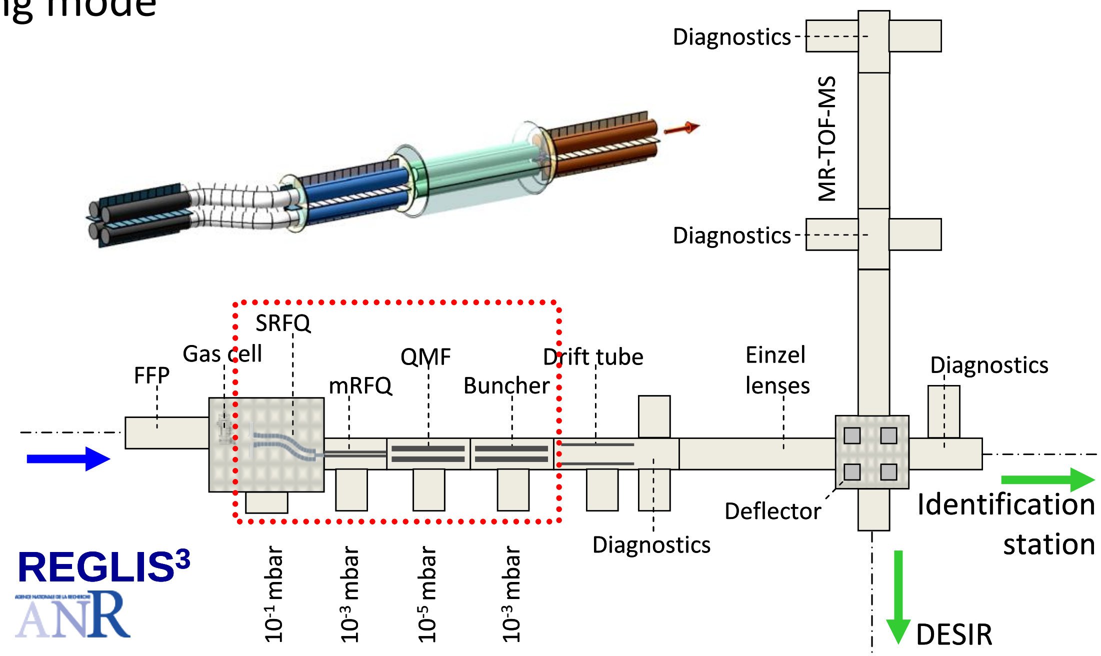


Optical modes

- High resolution mode (M/Q)
- High transmission mode (target position)
- High beam rejection mode (SHE)
- Converging mode

Low energy RIB

- Gas catcher (Ar, He)
- Laser re-ionization (high selectivity)
- Low energy mass separation
- Beam bunching
- MR-TOF-MS
  - Transfer line to DESIR
  - Identification station



REGLIS³
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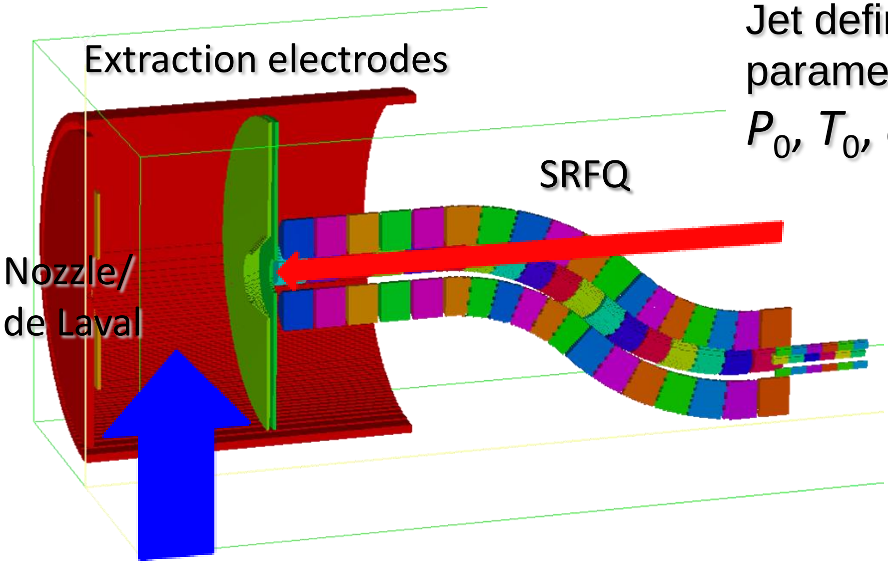
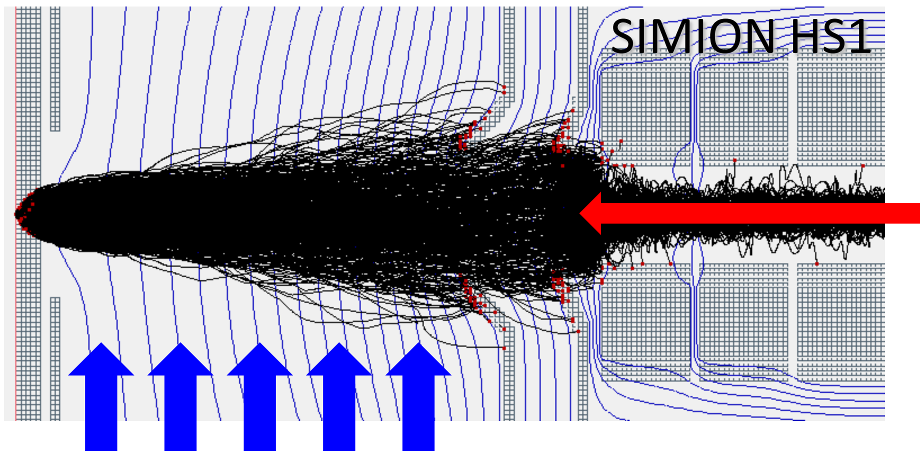
Free gas expansion jet definition for ion injection into RFQ



Jet definition parameters
P_0, T_0, d_0



$$M_z = x^{\frac{2}{3}}\left(3.232 - \frac{0.7563}{x} + \frac{0.3937}{x^2} - \frac{0.0729}{x^3}\right) \Rightarrow \rho_z = \left(1 + \frac{1}{3} M_z^{\ 2}\right)^{-\frac{3}{2}}$$

$$\rho_{\text{int}} = \rho_z \cos^2(\theta) \cos^2\left(\frac{\theta\pi}{2 \cdot 1.365}\right)$$

$$M_t = \sqrt{3 \cdot \left(\rho_{\text{int}}^{-\frac{2}{3}} - 1\right)}$$

$$\theta = \operatorname{atan2}(\sqrt{y^2 + z^2}, x)$$

$$\varphi = \operatorname{atan2}(y, z)$$

$$p = p_0\left(1 + \frac{1}{3} M_t^2\right)^{-\frac{5}{2}}$$

$$T = T_0\left(1 + \frac{1}{3} M_t^2\right)^{-1}$$

Jet-ions interaction in SIMION

$$V_f = \sqrt{\frac{5}{3} \frac{kT_0}{m} \frac{M_t}{\sqrt{1 + \frac{1}{3} M_t^2}}}$$

$$V_x = V_f \cos\theta$$

$$V_y = V_f \sin\theta \sin\varphi$$

$$V_z = V_f \sin\theta \sin\varphi$$

Yu. Kudryavtsev, *et al.*, Nucl. Instrum. Meth. B 297 (2013) 7

Inclusion of gas interactions and jet definition in SIMION

Setting of gas – ion interactions by using available add-ons

- Viscous drag (based on measured ion mobilities)
- Statistical Diffusion Similation (SDS)
- Hard sphere model (HS1)

Definition of gas jet properties

- Parameter maps from an external simulation (COMSOL, ANSYS, etc.)
- Parameter definition by functions directly in .lua

Required

Collision statistics file (SDS)

-- mbmr.dat –

Optional

Ion parameter definition file:

-- m_defs.dat – diameter, K_o by ion mass

Field definition files*:

-- p_defs.dat -- pressure field data (torr)

-- t_defs.dat -- temperature field data (K)

-- vx_defs.dat -- Vx gas velocity (m/s)

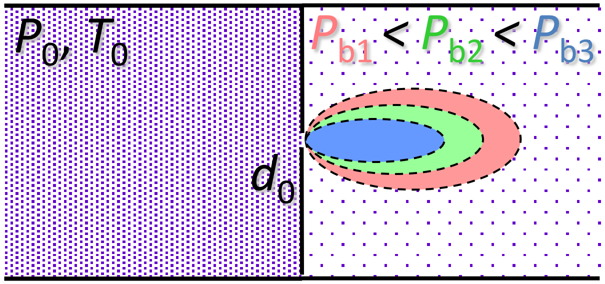
-- vy_defs.dat -- Vy gas velocity (m/s)

-- vz_defs.dat -- Vz gas velocity (m/s)

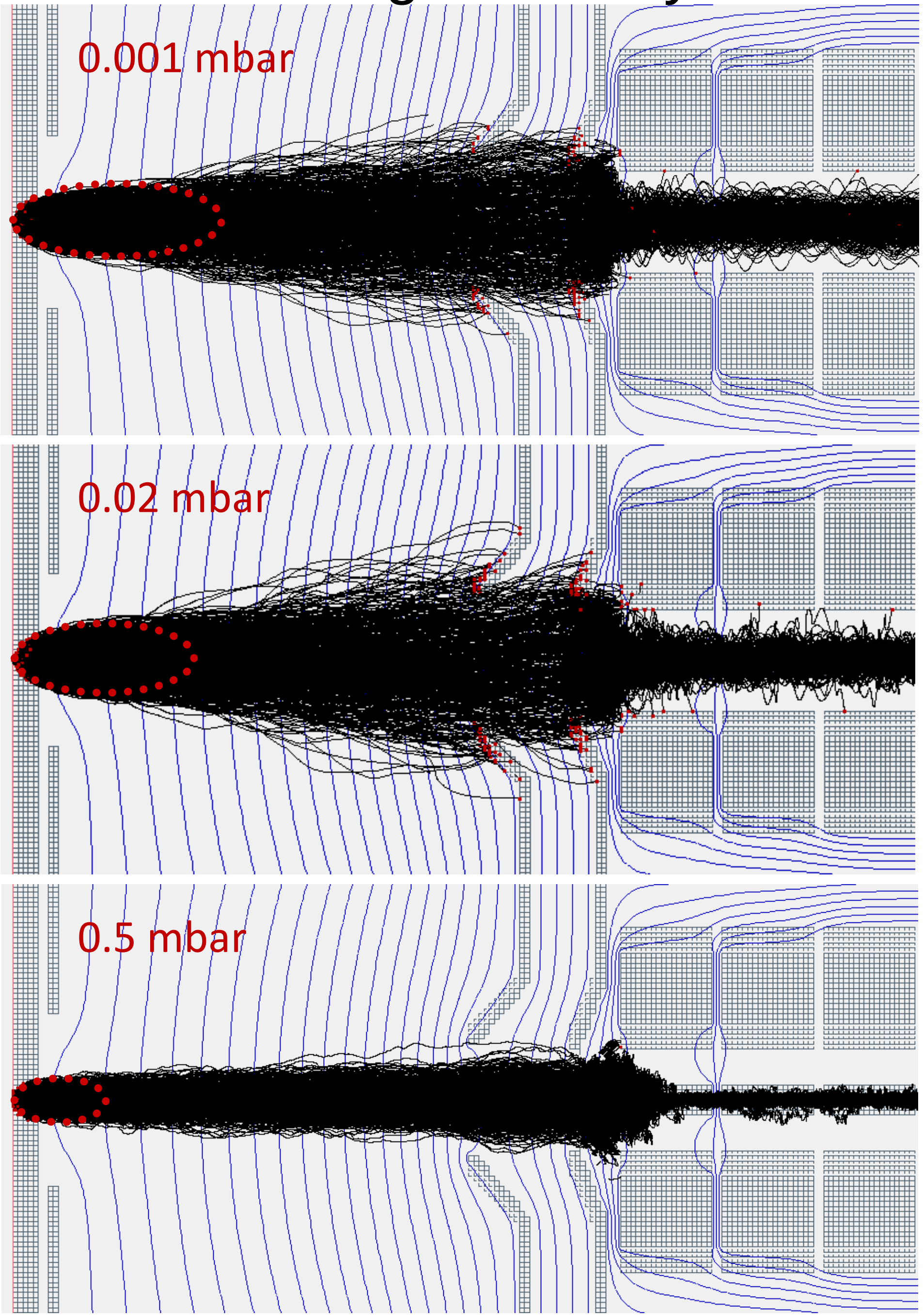
*each file must have the same dimensions as the associated potential array

Combination of gas jet and background gas pressure

- Definition of an equal probability surface
- Definition of overlapping region due to atom-atom interactions (gas jet – background)

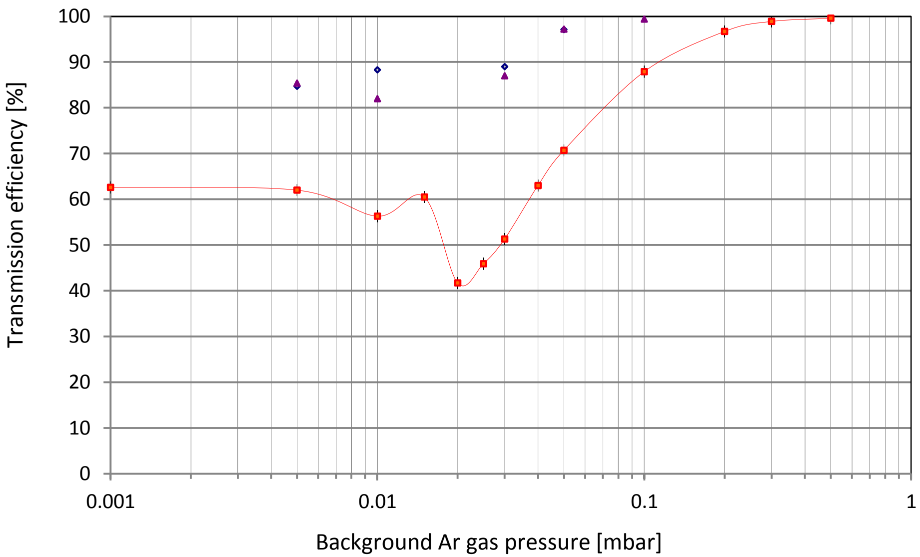


Loading efficiency vs. Ar background pressure (HS1)

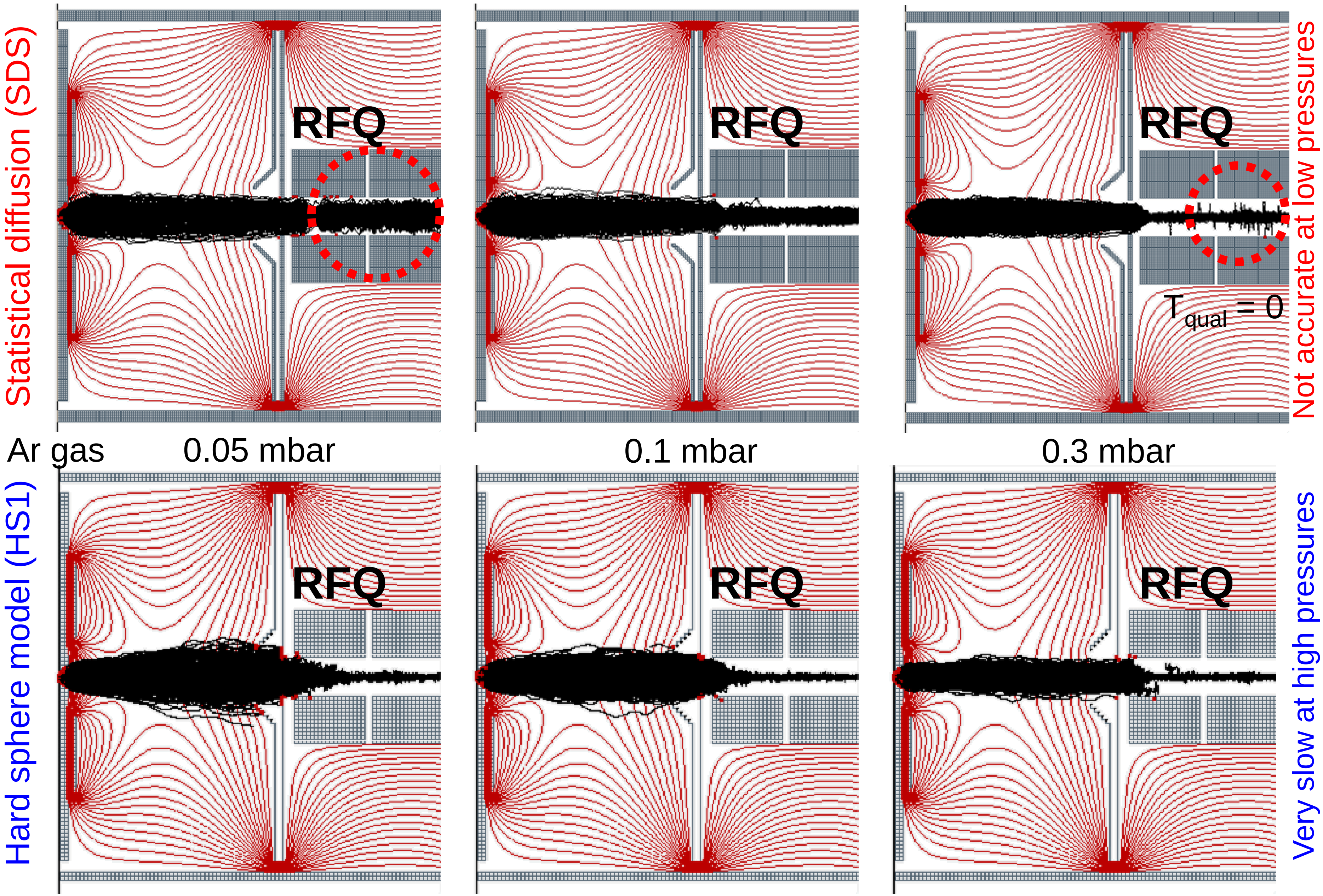


Optimization of parameters vs. pressure

- Position of injection electrodes
- Angle of second injection electrode
- Apertures of injection electrodes
- Position and size of entrance RF segments
- DC and RF potentials

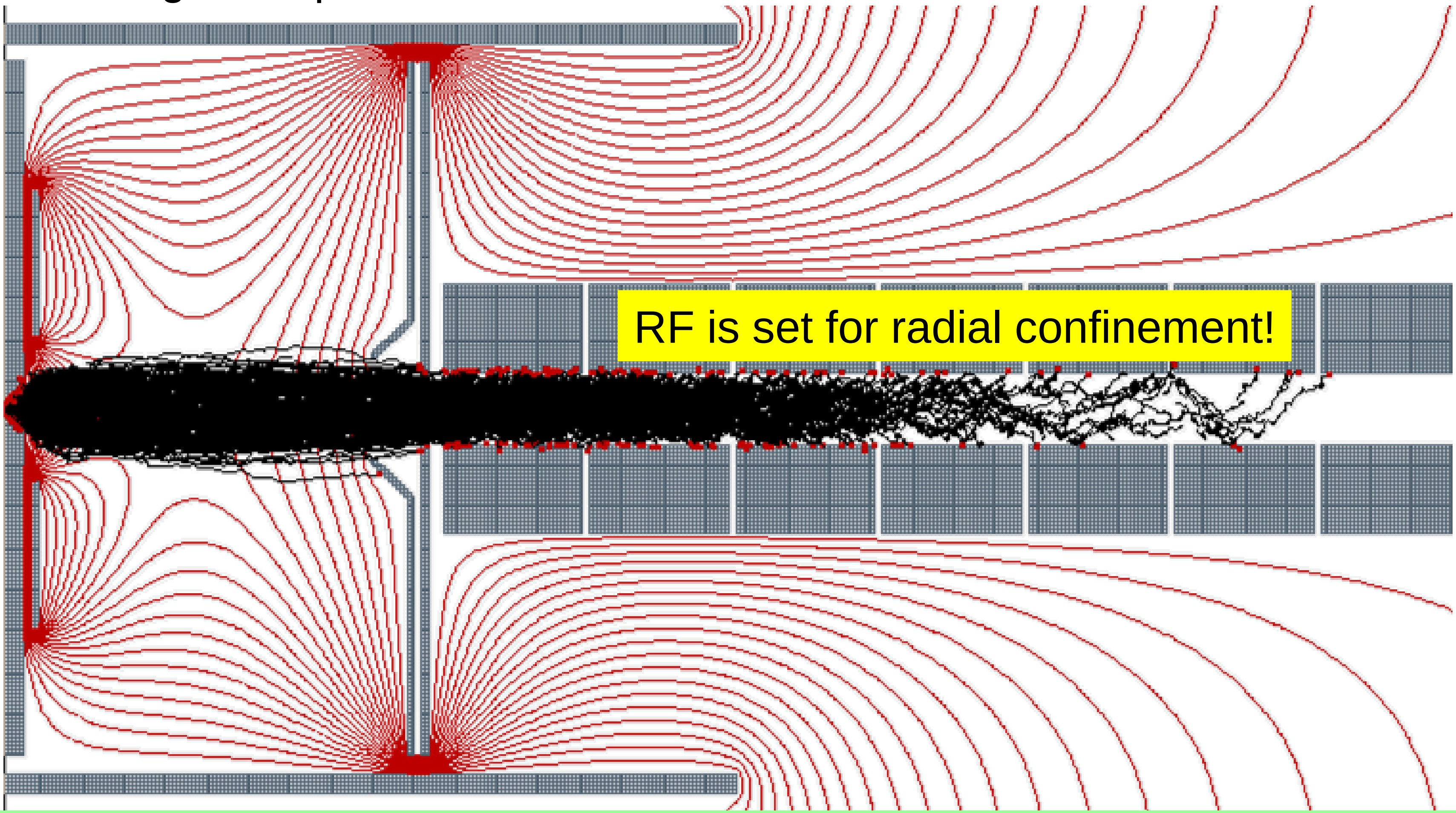


Gas interaction models in SIMION – SDS vs HS1



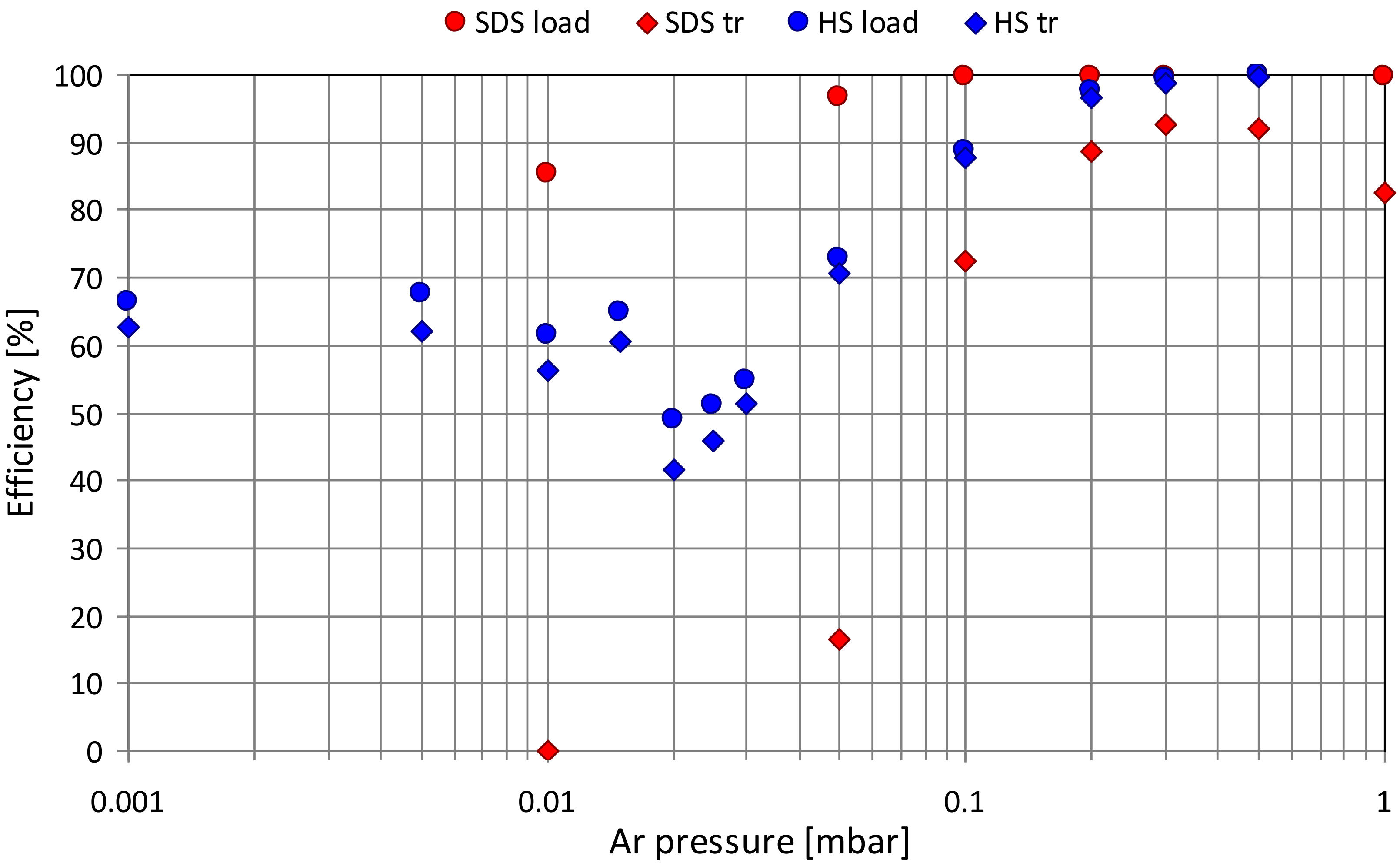
SDS model with RF electric fields at low background pressures

Ar background pressure 0.01 mbar

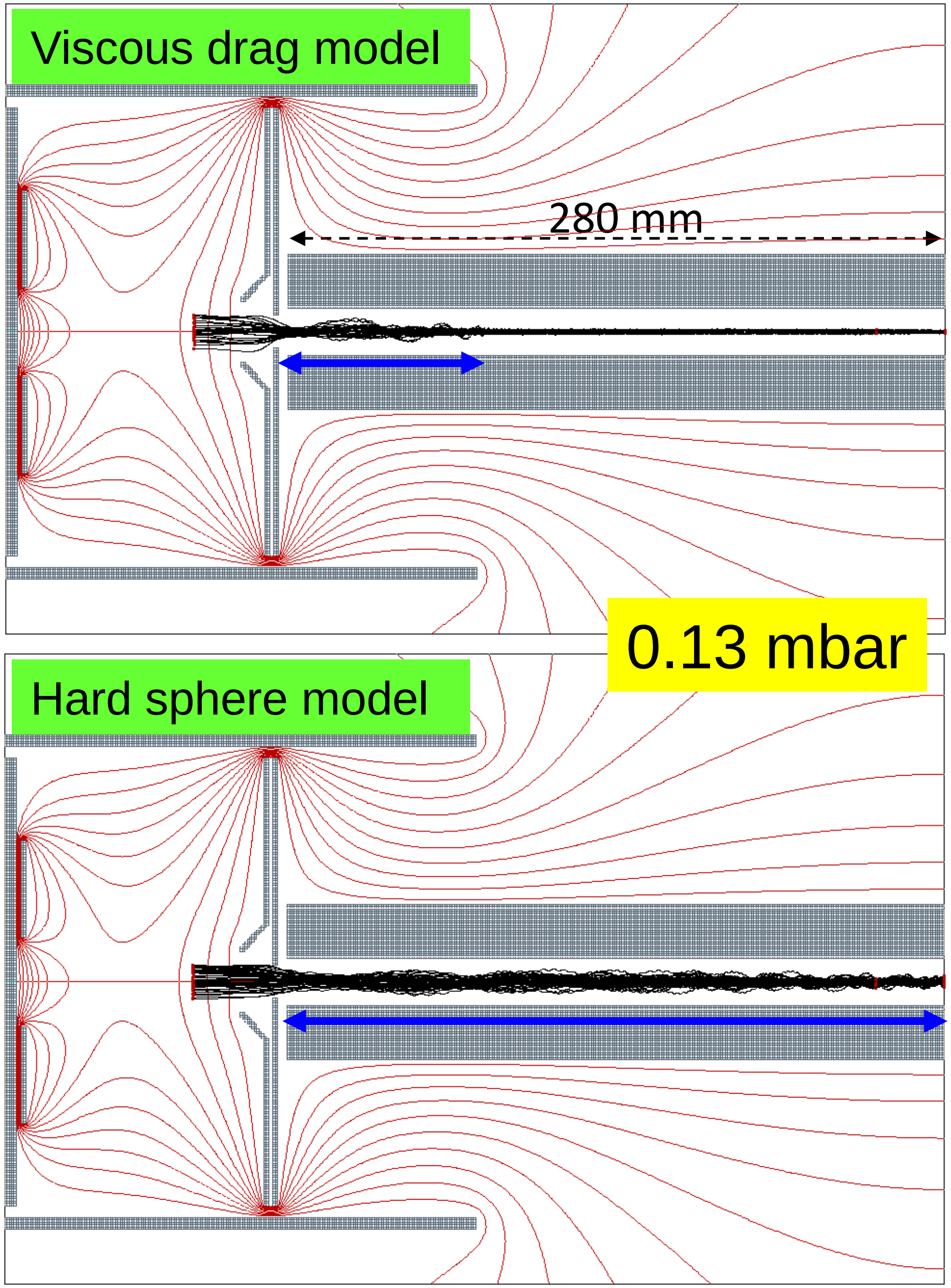


”The statistical diffusion simulation (SDS) user program avoids the computationally intensive issues of high collision rates by employing collision statistics to simulate the effects of millions of collisions per time step. Ion motions are simulated by a combined viscous ion mobility and random ion jumping approach.”

Efficiencies vs. background pressure



Viscous drag vs. HS1 - pressure comparison



- Rb^+ ions (A = 85)
- Same input distribution
- RFQ parameters:
  - RF: 500 V / 2 MHz
  - r_0 = 10 mm

Viscous drag model parameters for helium gas
A = 4
T = 300 K
k_0 = 20.0 (measured)
p = 0.097 Torr = 1.3×10^{-1} mbar

Same pressure

HS model parameters for helium gas
A = 4
Sigma = 2.68×10^{-19} mm² (calc.)
p = 3.0 Pa = 1.3×10^{-1} mbar
T = 300 K

Cooling is stronger in viscous model than in HS model for same pressure

SUMMARY

- Viscous drag model cools infinitely unless a limit is set – not useful for thermal ions
- SDS is unreliable at low pressures (<0.05 mbar)
- SDS with RF is unreliable (or needs adjustments) at high pressures (>0.5 mbar)
- HS1 requires higher pressure compared to viscous drag for similar radial cooling (Ar, He)
    - HS model depends on cross sections which require knowledge of radii
- HS1 can be used without computing time restrictions for pressures up to 0.5 mbar
- Comparison of SDS, HS1 and viscous drag models is important