ELECTRON AND POSITRON SCATTERING AND TRANSPORT IN SIMPLE LIQUIDS

GREGORY BOYLE, BOB MCEACHRAN, DANIEL COCKS,
WADE TATTERSALL AND RON WHITE

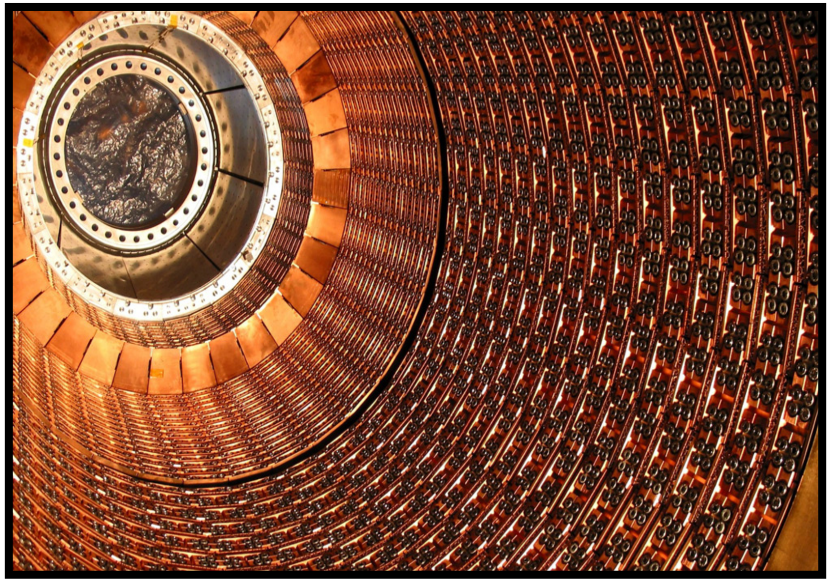
COLLEGE OF SCIENCE AND ENGINEERING, JCU, TOWNSVILLE, QLD, AUS

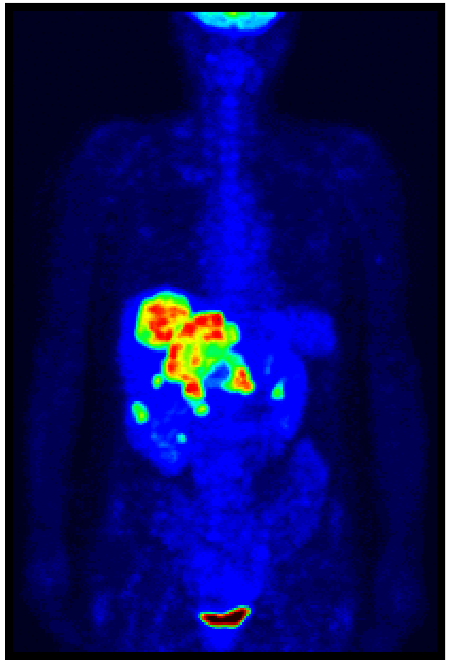
FOCUS OF THIS TALK

- Motivation
- Modelling: Kinetic Theory
- From dilute gases to dense gases/liquids: The effect of density
  - Electrons
  - Positrons
- Ionization: electrons vs positrons

MOTIVATION

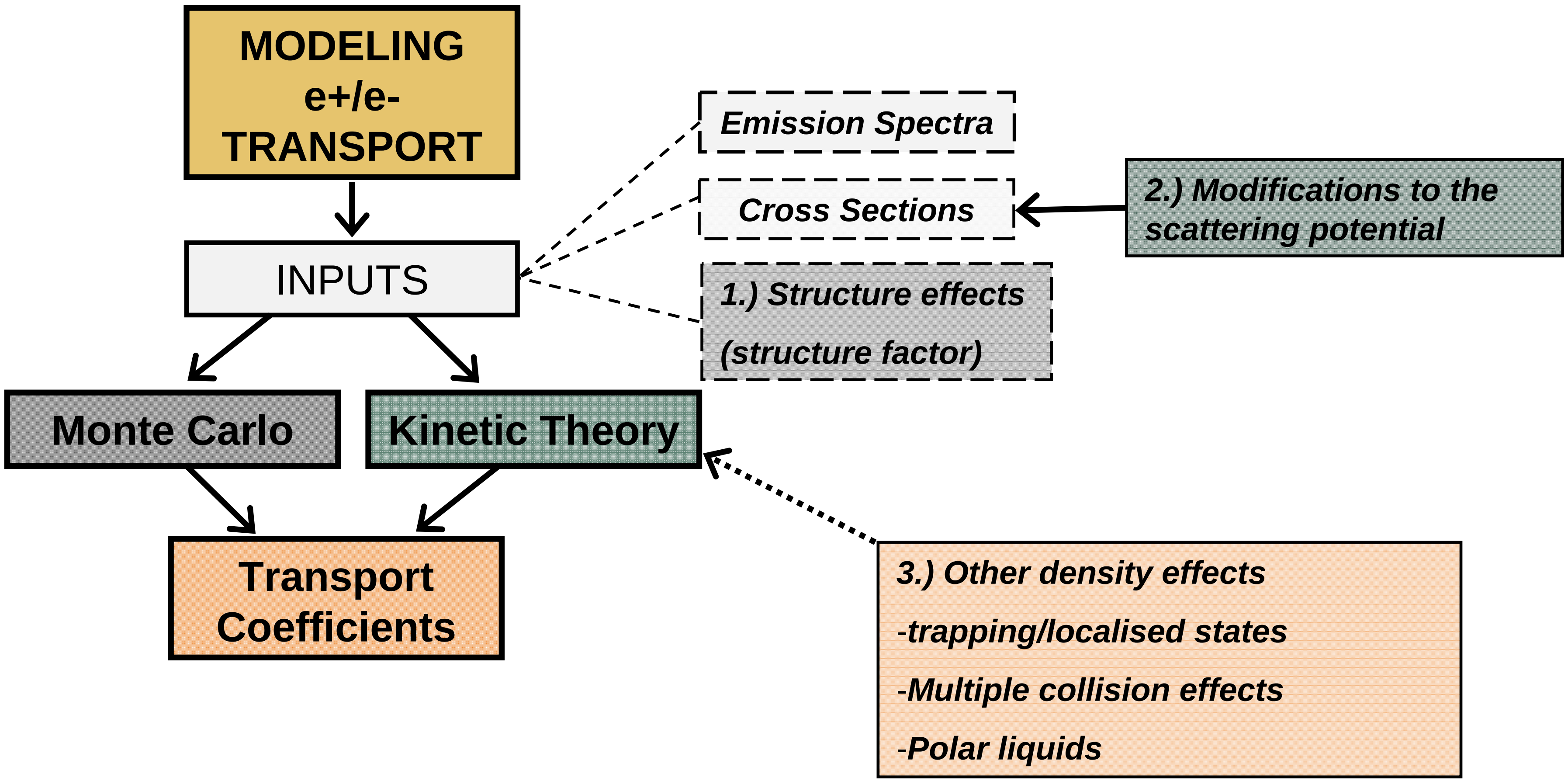
Study of e- and e+ in gas and liquid systems is of both fundamental interest and for technological applications:





Program at JCU

OWARDS A TRANSPORT MODEL IN DENSE GASES/LIQUIDS

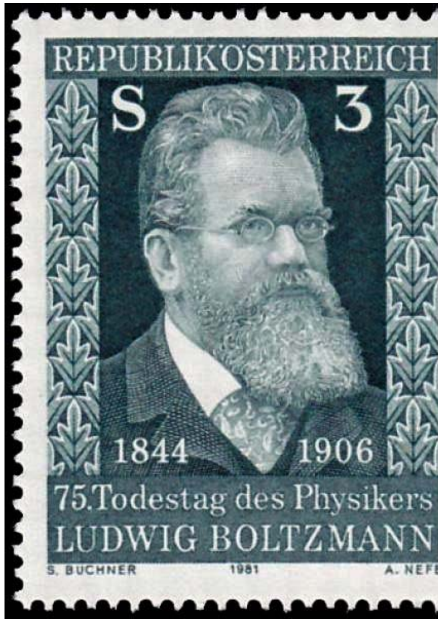


KINETIC THEORY

The branch of statistical mechanics that describes systems through a *phase-space* distribution $f(\boldsymbol{r}, \boldsymbol{v}, t)$

Boltzmann's equation:

$$\frac{\partial f}{\partial t} + \boldsymbol{v} \cdot \nabla f + \boldsymbol{a} \cdot \frac{\partial f}{\partial \boldsymbol{v}} = -J(f)$$



- $\boldsymbol{r}, \boldsymbol{v}$ = space and velocity coordinates
- $\boldsymbol{a}$ = acceleration from external forces (e.g. Applied Electric Field)
- $J(f)$ = collision operator = $J_{elas}(f) + J_{ann}(f) + J_{exc}(f) + J_{ion}(f)$ ...
- $f(\boldsymbol{r}, \boldsymbol{v}, t)$ is generally Non-Maxwellian

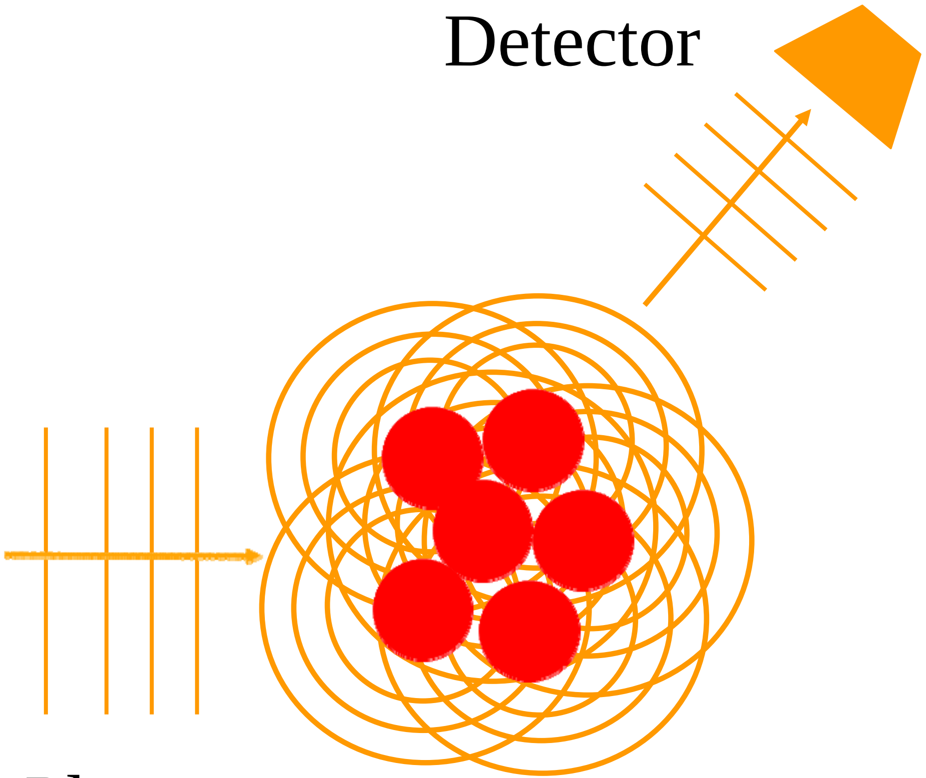
Macroscopic quantities from microscopic information

- Require averages, e.g.

$$W = \frac{1}{n} \int \boldsymbol{v} f d\boldsymbol{v}$$

$$Z_{eff} \propto \frac{1}{n} \int \vartheta_{ann}(f) d\boldsymbol{v}$$

.) STRUCTURE EFFECTS: COHERENT SCATTERING

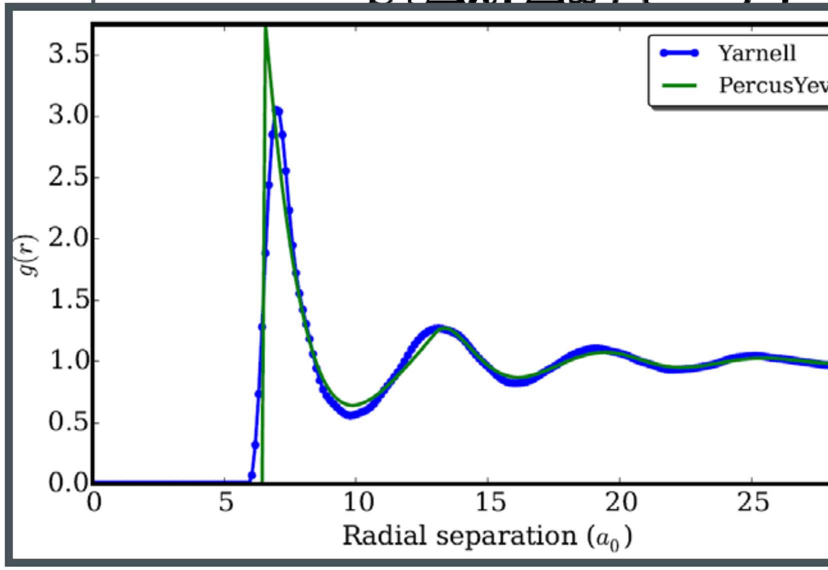


Plane
wave

$$S(\mathbf{K}) = 1 + \rho \int d\mathbf{r} \;\; \exp\left(-i\mathbf{K}\mathbf{r}\right) \left[g(\mathbf{r}) - 1\right]$$

Dynamic structure factor
- properties of the medium or

$$\frac{d^2\sigma}{\ldots} = S(\Delta \boldsymbol{k}, \Delta\omega) \left(\frac{d\sigma}{\ldots} \right)^{(l}$$



L. Van Hove (1957), M. H. Cohen and J. Lekner (1

2.) MODIFICATION OF SCATTERING POTENTIAL

Lekner 1967 formalism

- Updated with modern techniques

Screening of polarization potential

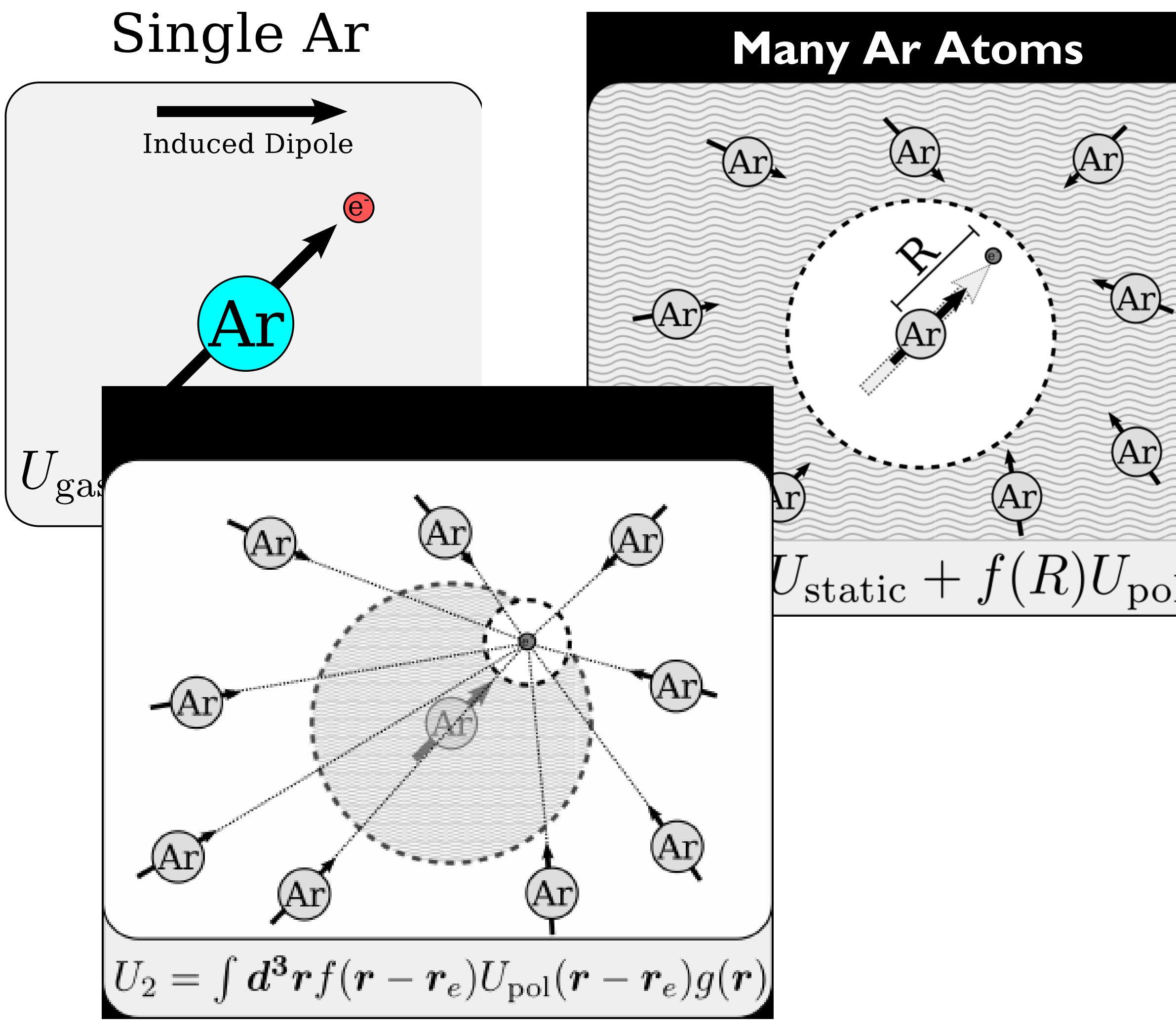
- Screening function $f(R)$

Average potential

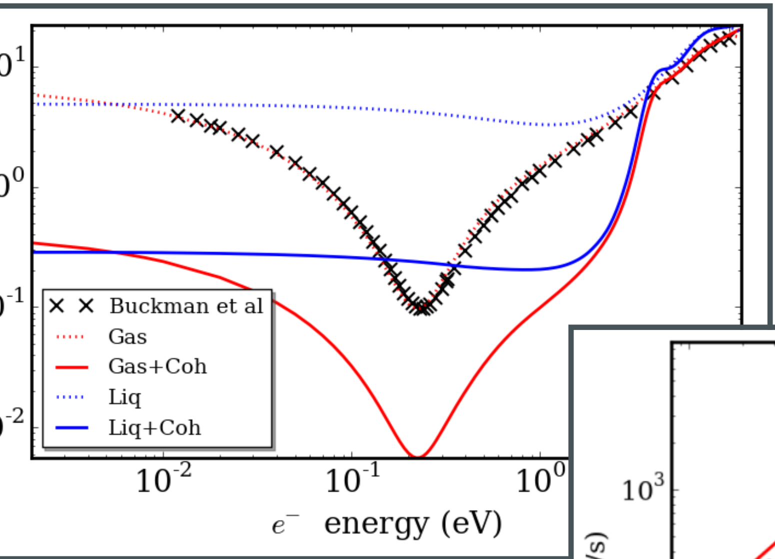
- $U_{eff} = U_1 + U_2$

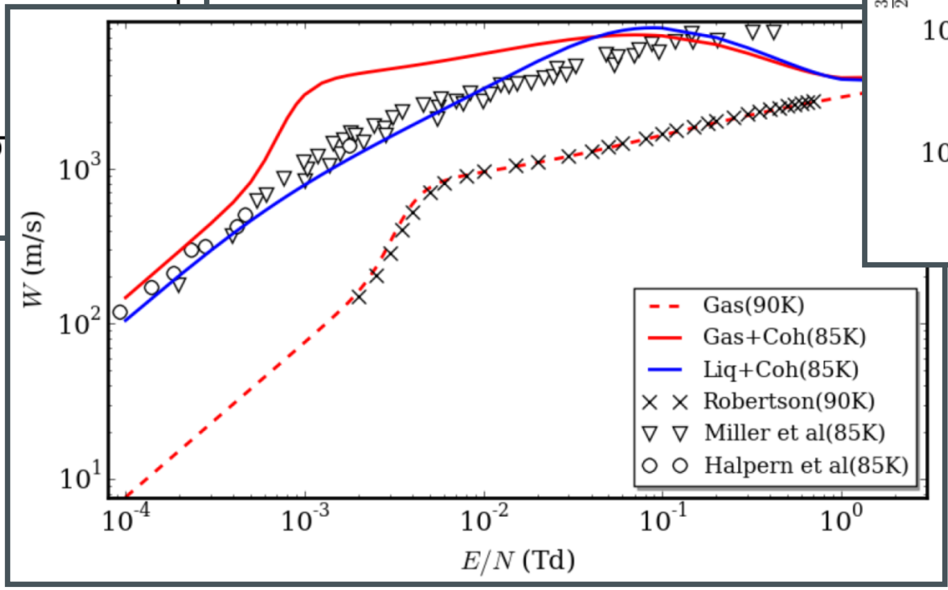
Cross sections from U_{eff}

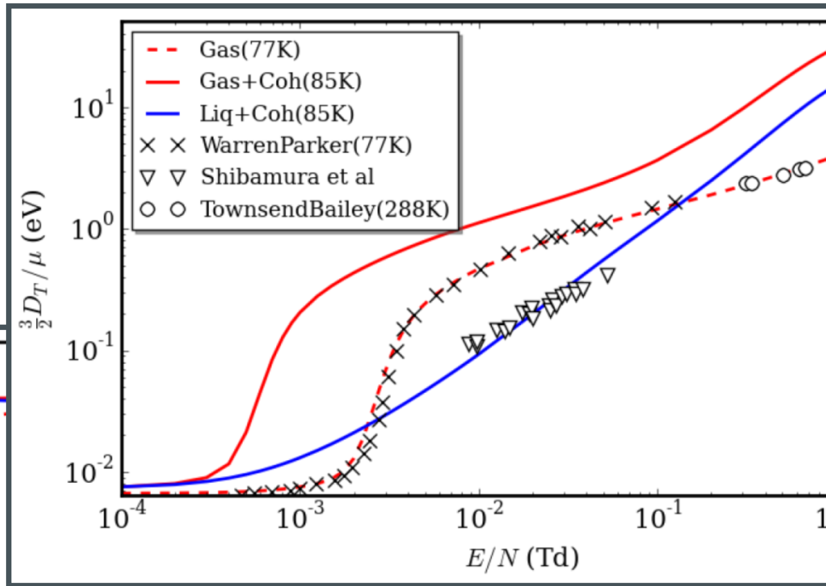
- Region "owned" by an atom ($r < r_m$)



RESULTS: ELECTRONS IN LIQUID ARGON







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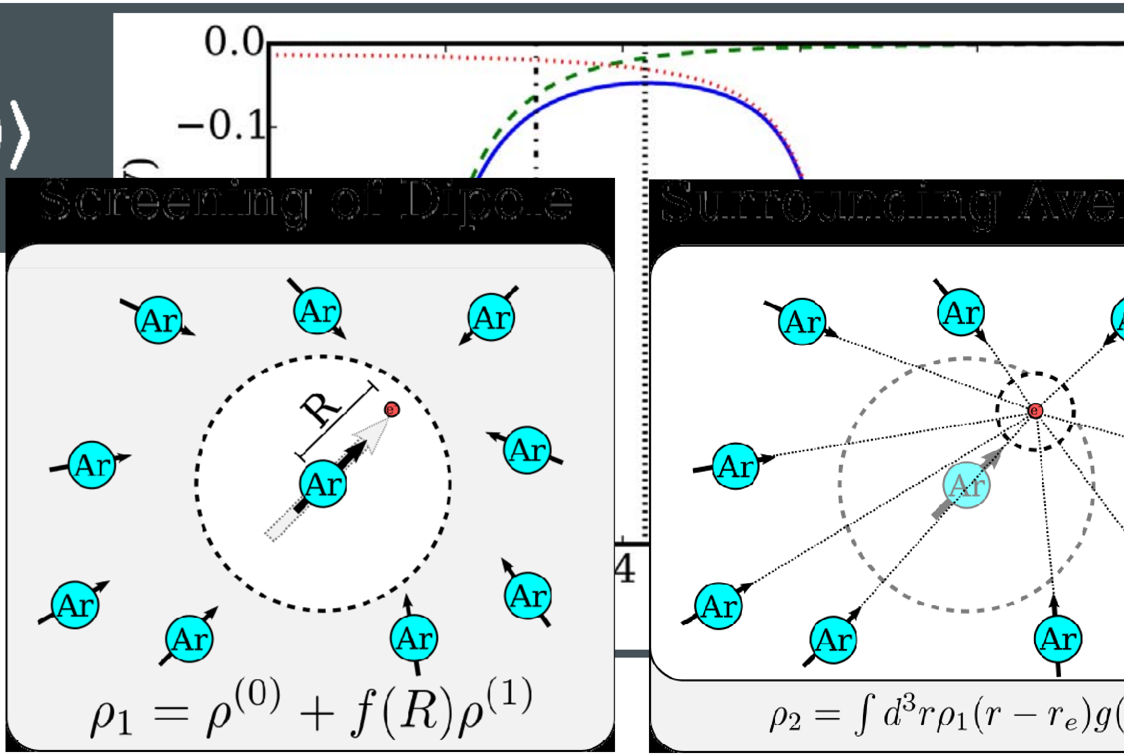
POSITRONS IN LIQUIDS - $r_m, \langle\rho(r)\rangle$



Need to define the r_m differently

- Static potential sign change
  - $\longrightarrow$ no stationary point (Lekner theory e-)
- Match incoming wave packet (V_{shift})

Alternative approaches

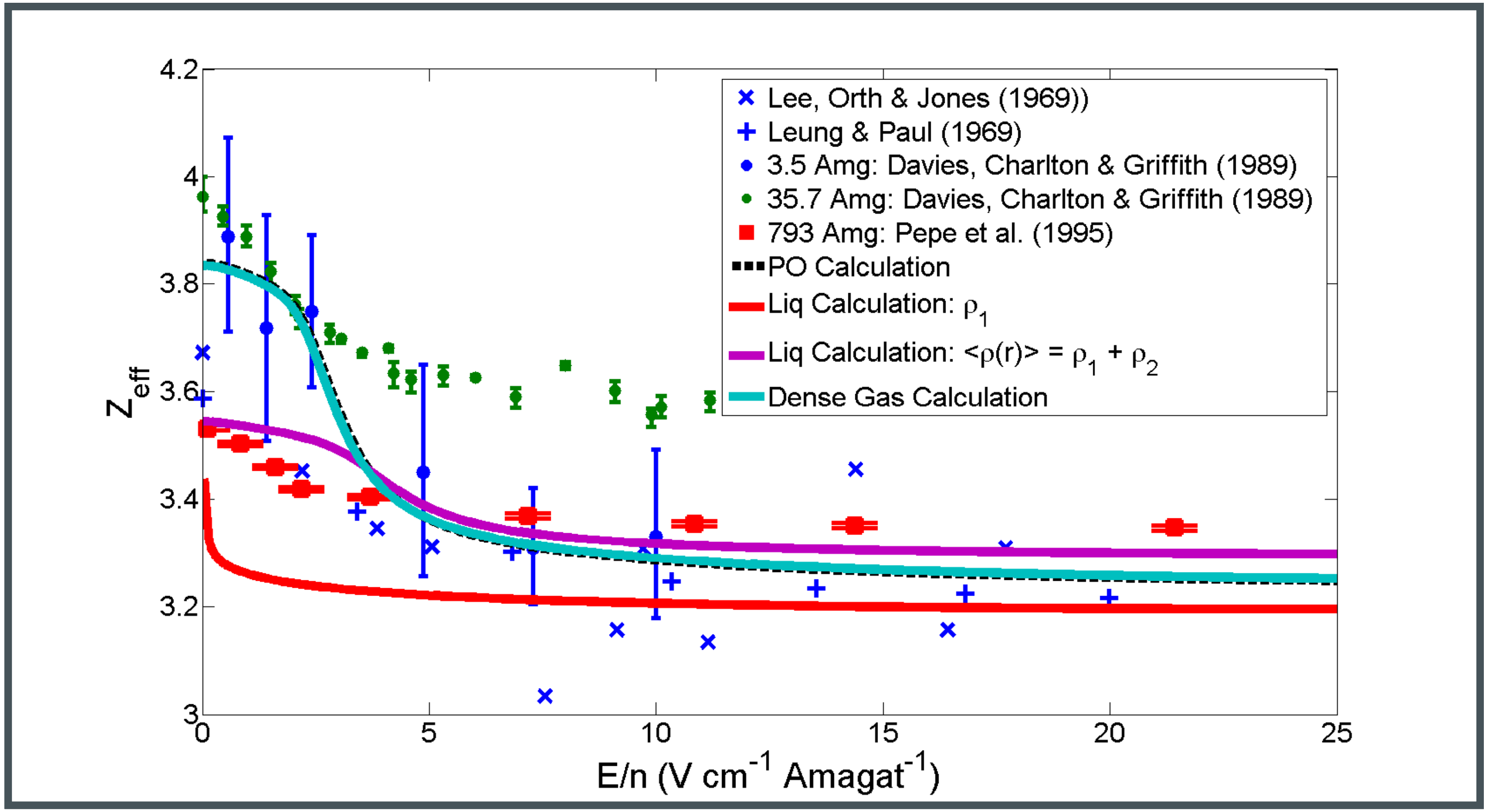
- Wigner-Setiz radius, features of the potential e.g. zeros

Two contributions to annihilation in a scattering event

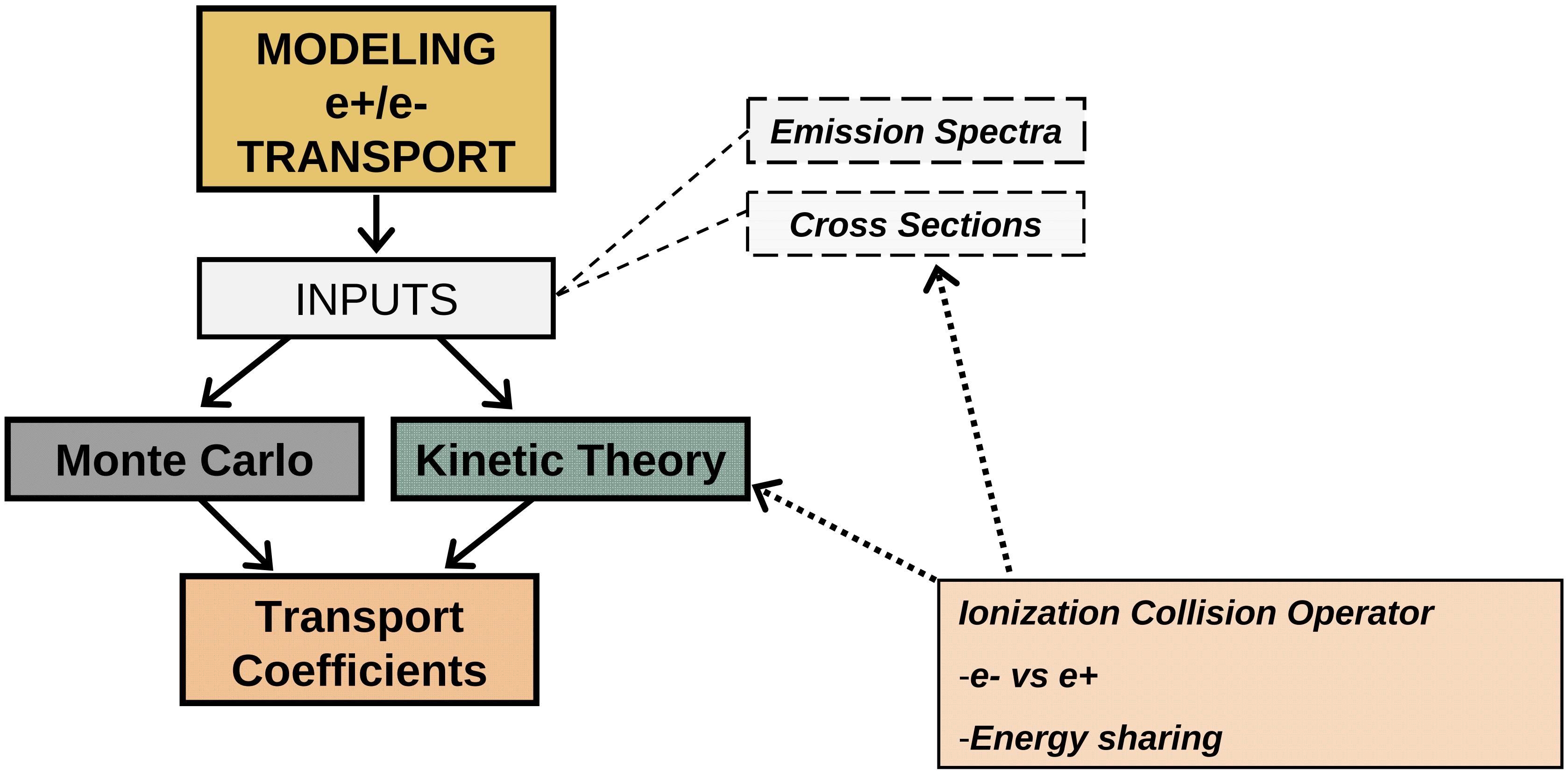
- Annihilation with target atom
- Annihilation with surrounding atoms
- Define an "ensemble Average Charge Density" $\langle\rho(r)\rangle$
- $\langle\rho(r)\rangle = \rho_1 + \rho_2$

		V_{shift} Choice		
r_m Choice		0	U_{eff}	
	WS	High	Low	
	RL	High	Low	
	SZ	High		
	ESP	High		

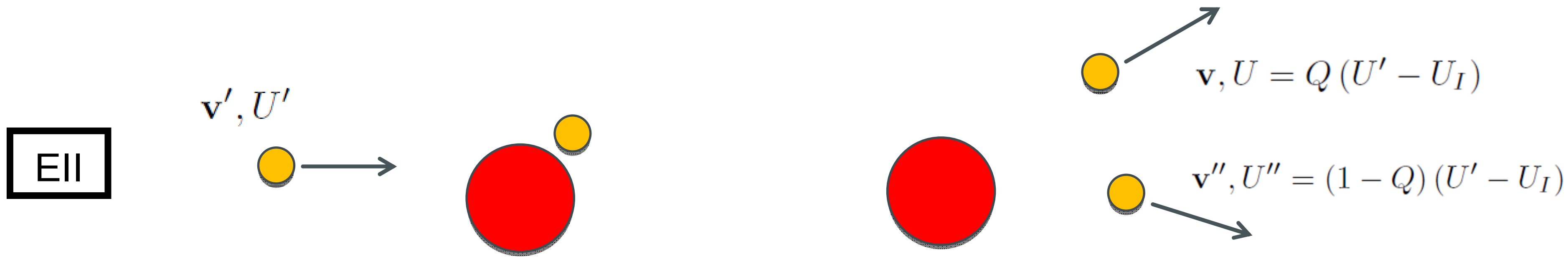
RESULTS: POSITRONS IN LIQUID HELIUM



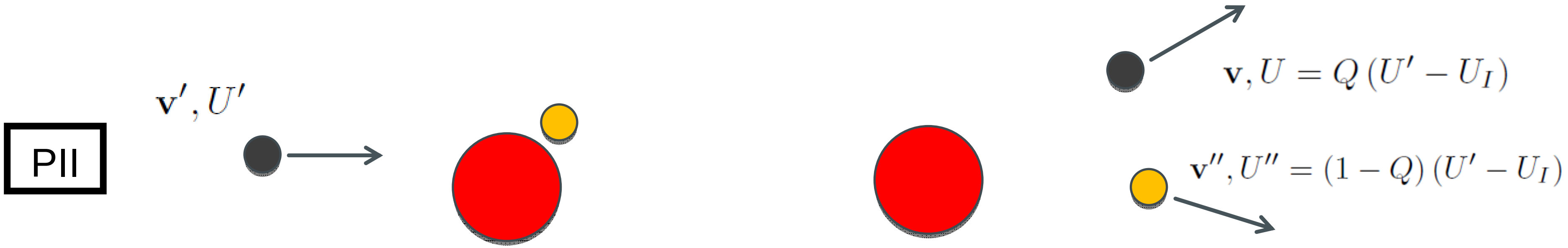
RANSPORT MODEL INCLUDING IONIZATION



ONIZATION COLLISION OPERATOR



$$J^{\mathrm{ion}} = n_0 v \sigma^{\mathrm{ion}}(v) f(\mathbf{r}, \mathbf{v}, t) - 2n_0 \int v' \sigma^{\mathrm{ion}}(v') B(\mathbf{v}, \mathbf{v}') f(\mathbf{r}, \mathbf{v}', t)\, d\mathbf{v}'$$



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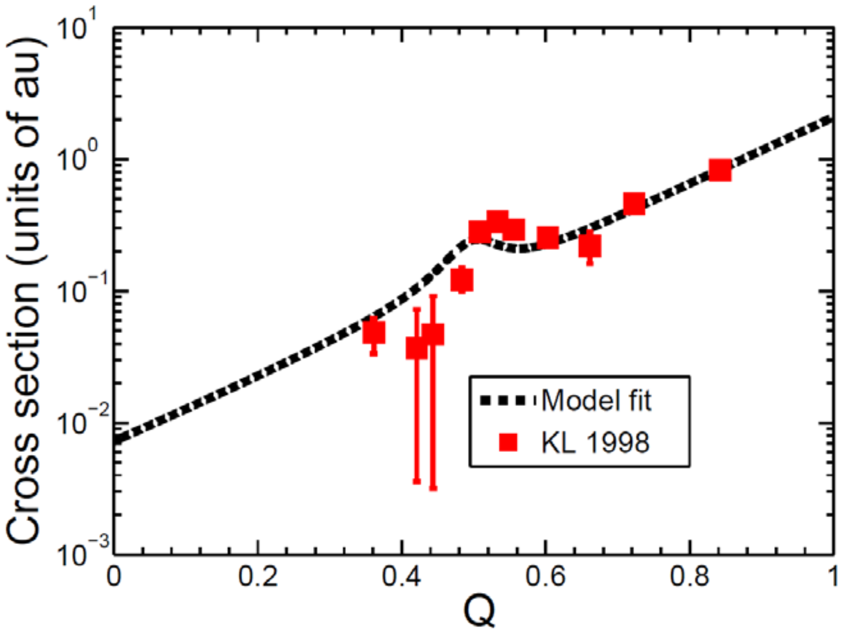
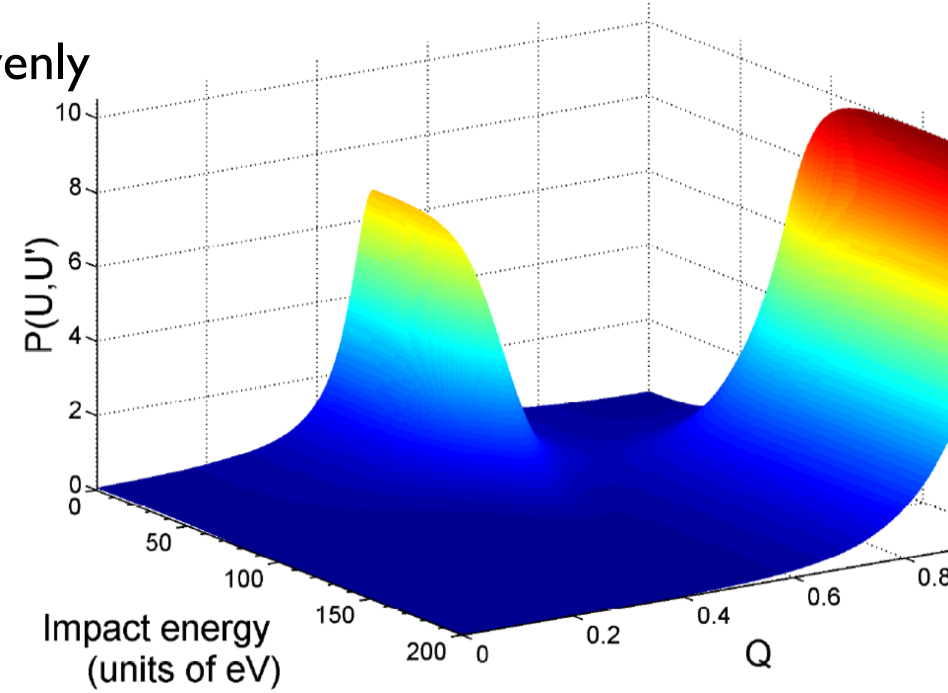
POSITRON-IMPACT IONIZATION IN H_2

y-partitioning function, P(U,U')

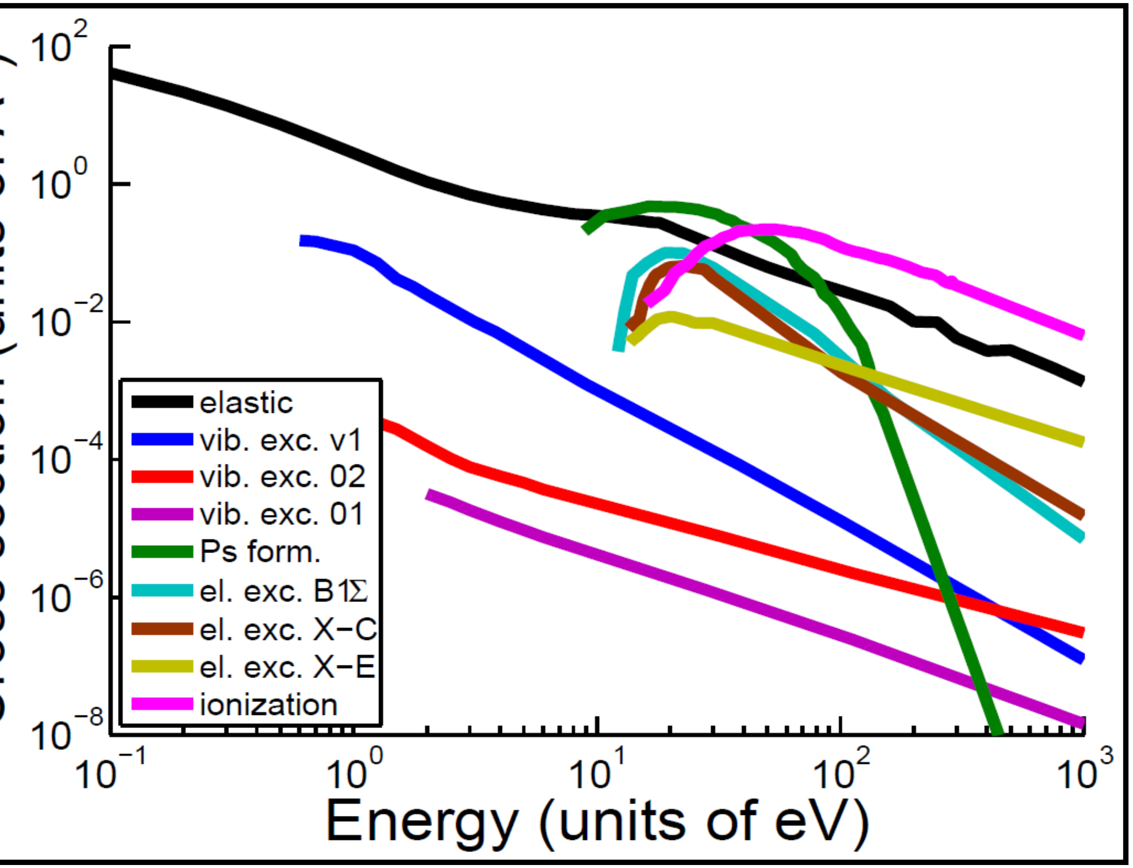
- High impact energies: e+ gets most of the energy
- Near-threshold impact energies: e+ and e- share energy evenly
- Model can be fit to experimental data (e.g. H_2)

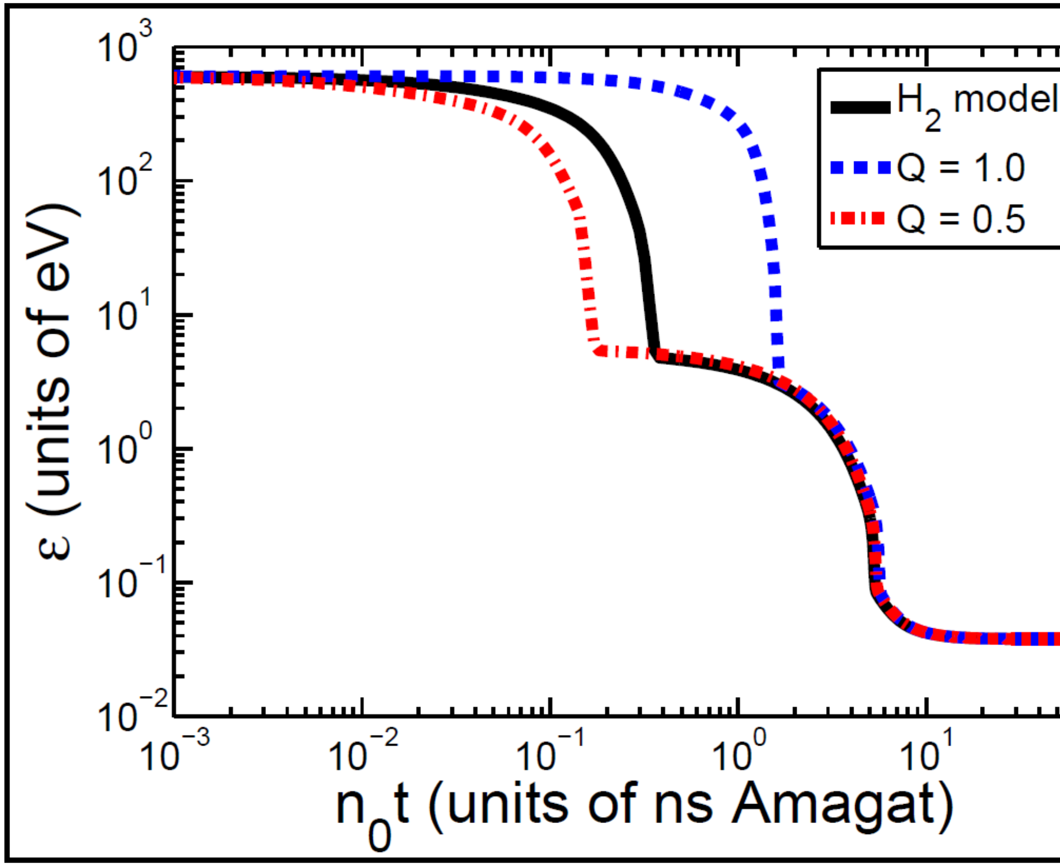




Kover and Laricchia, *Phys. Rev. Lett.* **80**, 5309 (199

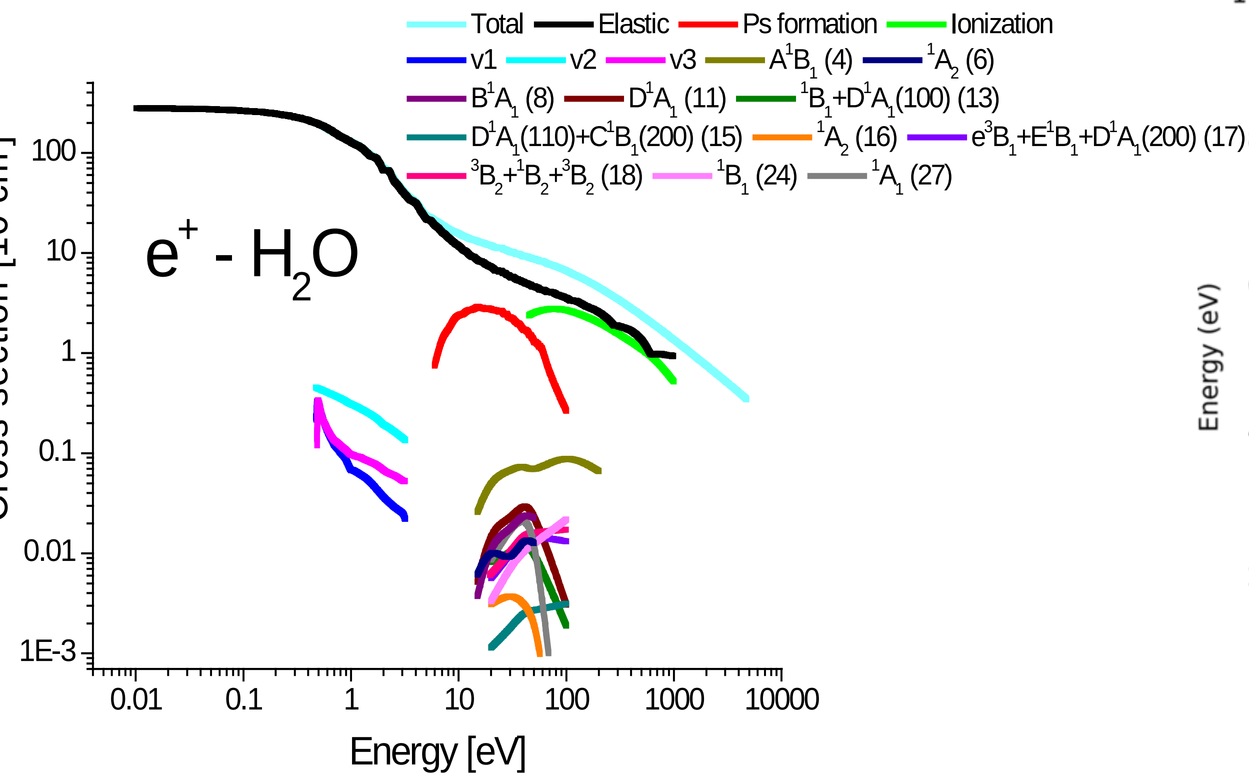
POSITRON-IMPACT IONIZATION IN H_2

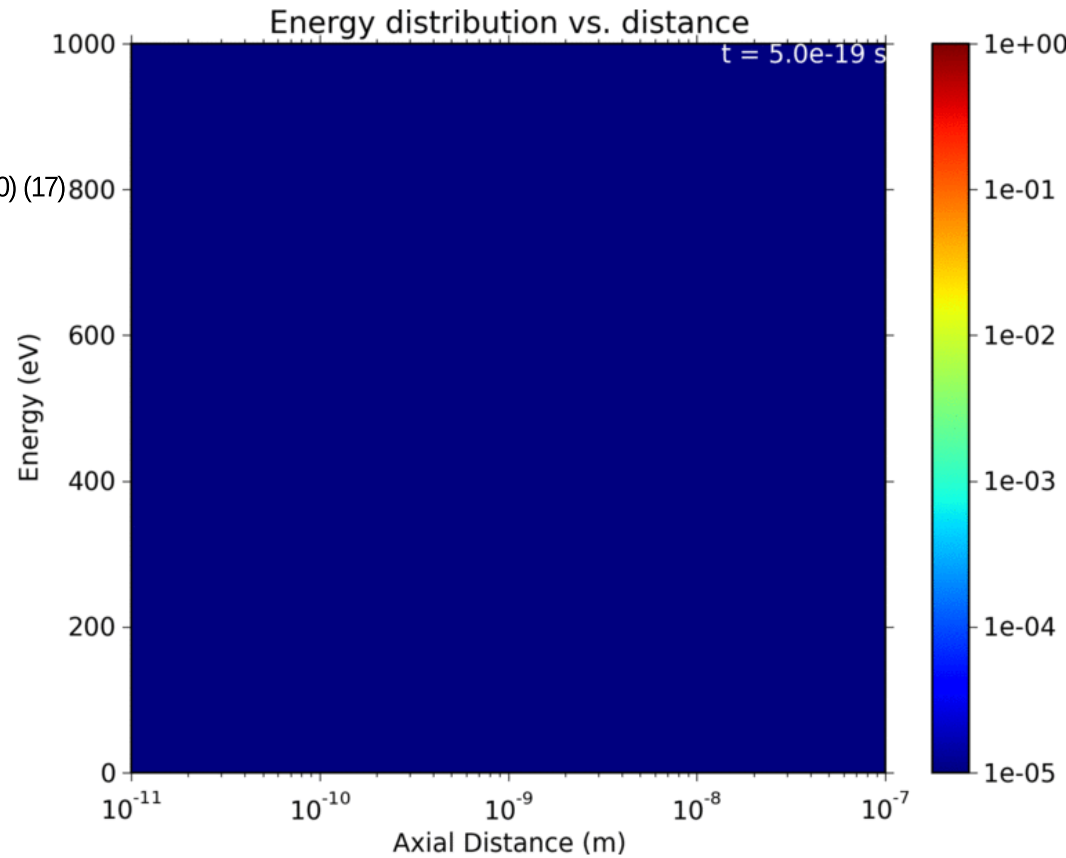




Compiled by Belgrade Group: see G Boyle et al. Phys. Rev. A (20

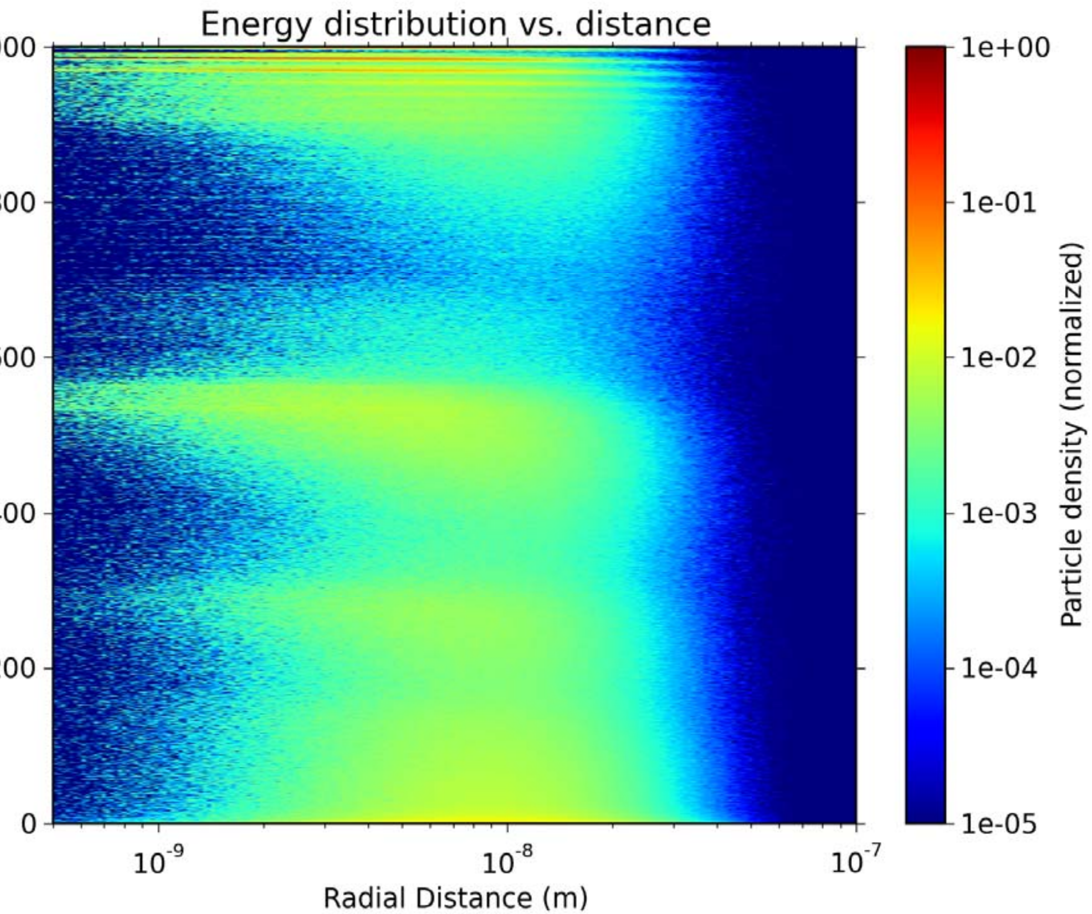
POSITRON-IMPACT IONIZATION IN H_2O

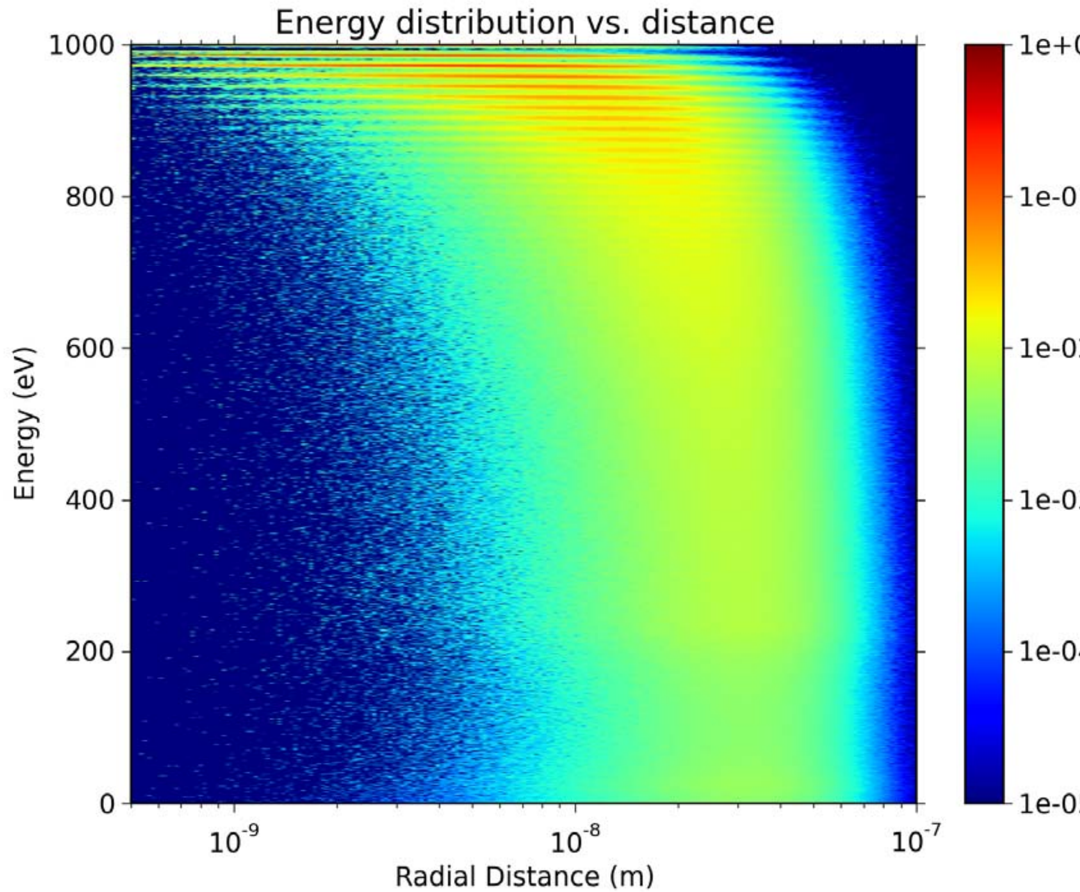




A Bankovic et al. New J. Phys. (2012)

SENSITIVITY TO IONIZATION ENERGY SHARING





FUTURE WORK

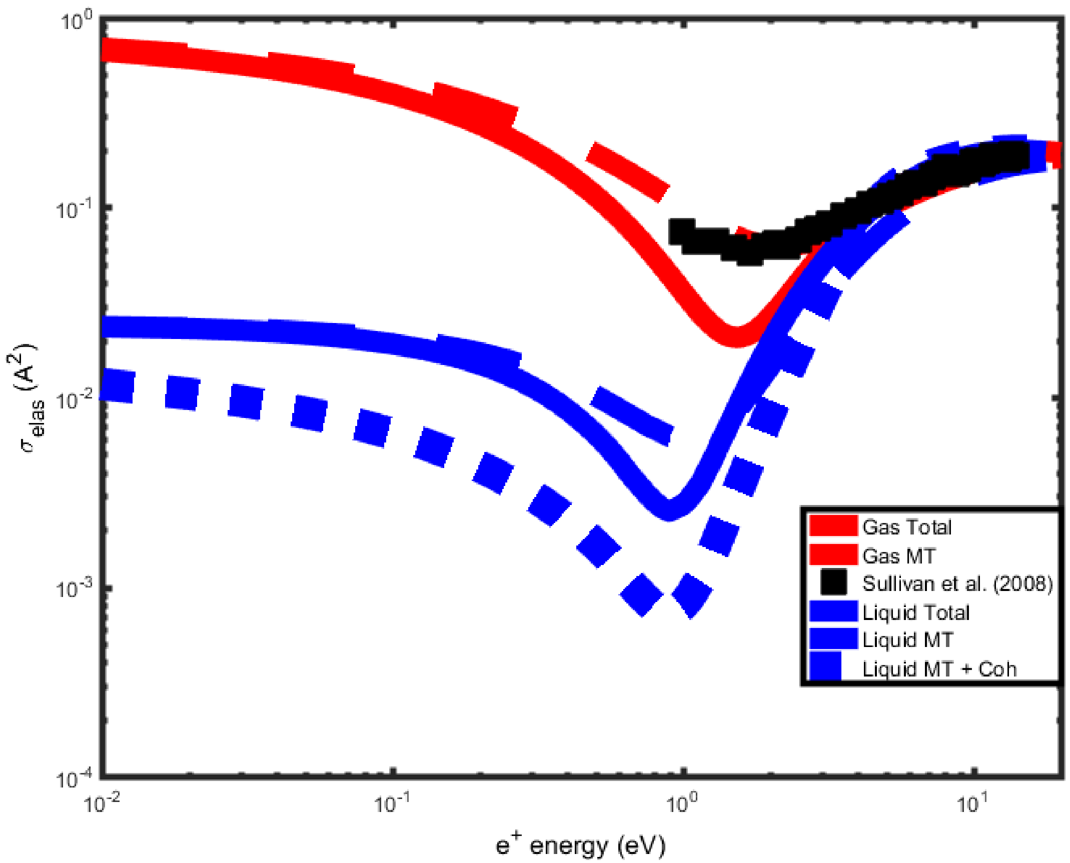
Transport in Gases ≠ Transport in Liquids

Ionization Energy Sharing: e+ more sensitive than e-

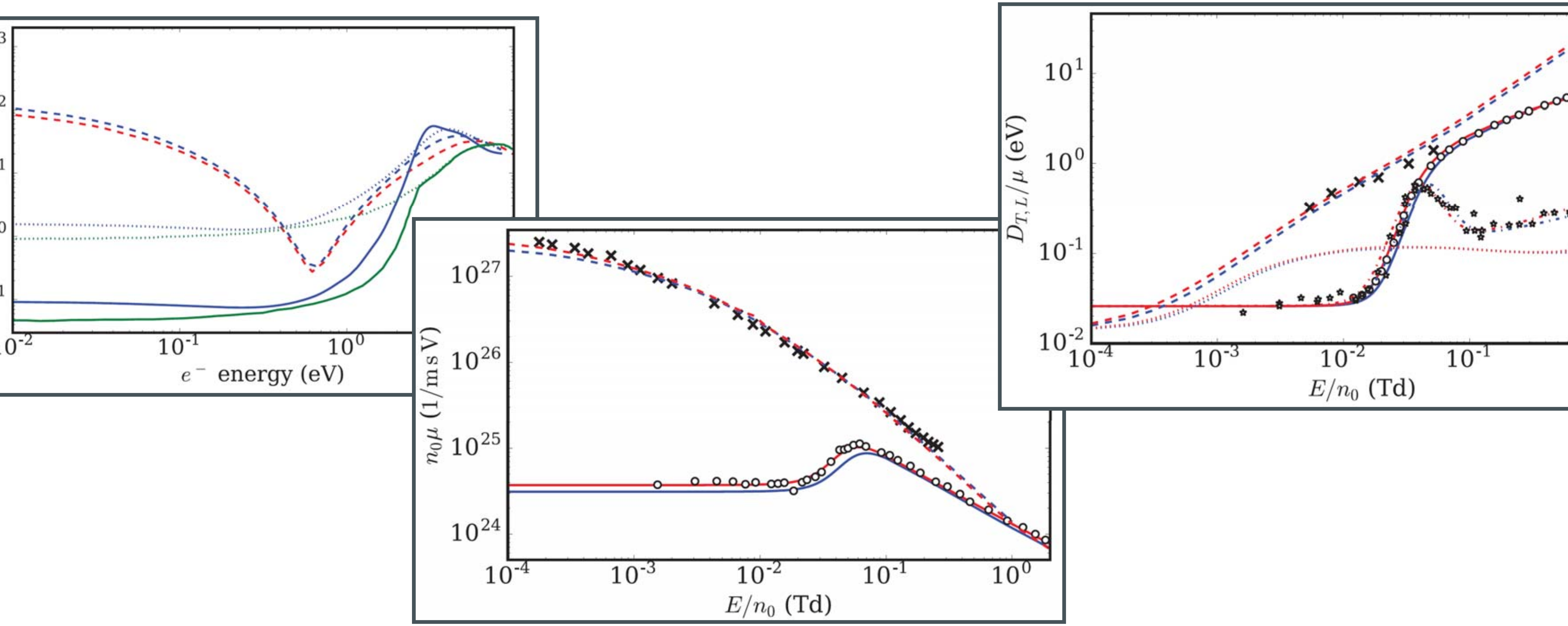
- Electrons and Positrons in other Noble gas liquids – Ar, Kr, Xe
- Positronium formation in liquids
- Bubbles, clusters, and other density effects
- Polar liquids, Biological Matter

THANK YOU FOR LISTENING!

POSITRONS IN LIQUID HELIUM



RESULTS: ELECTRONS IN LIQUID XENON



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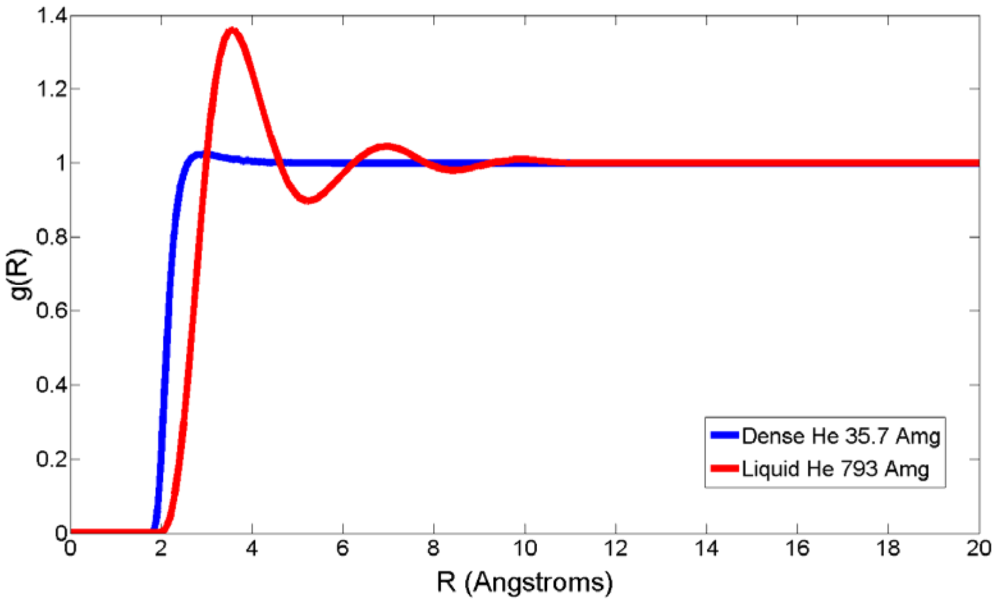
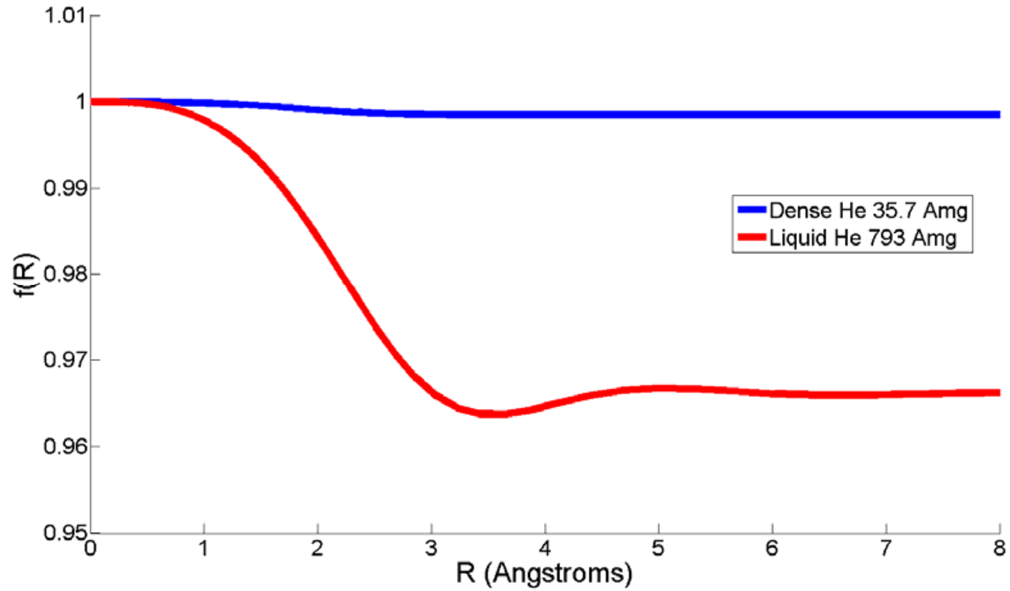
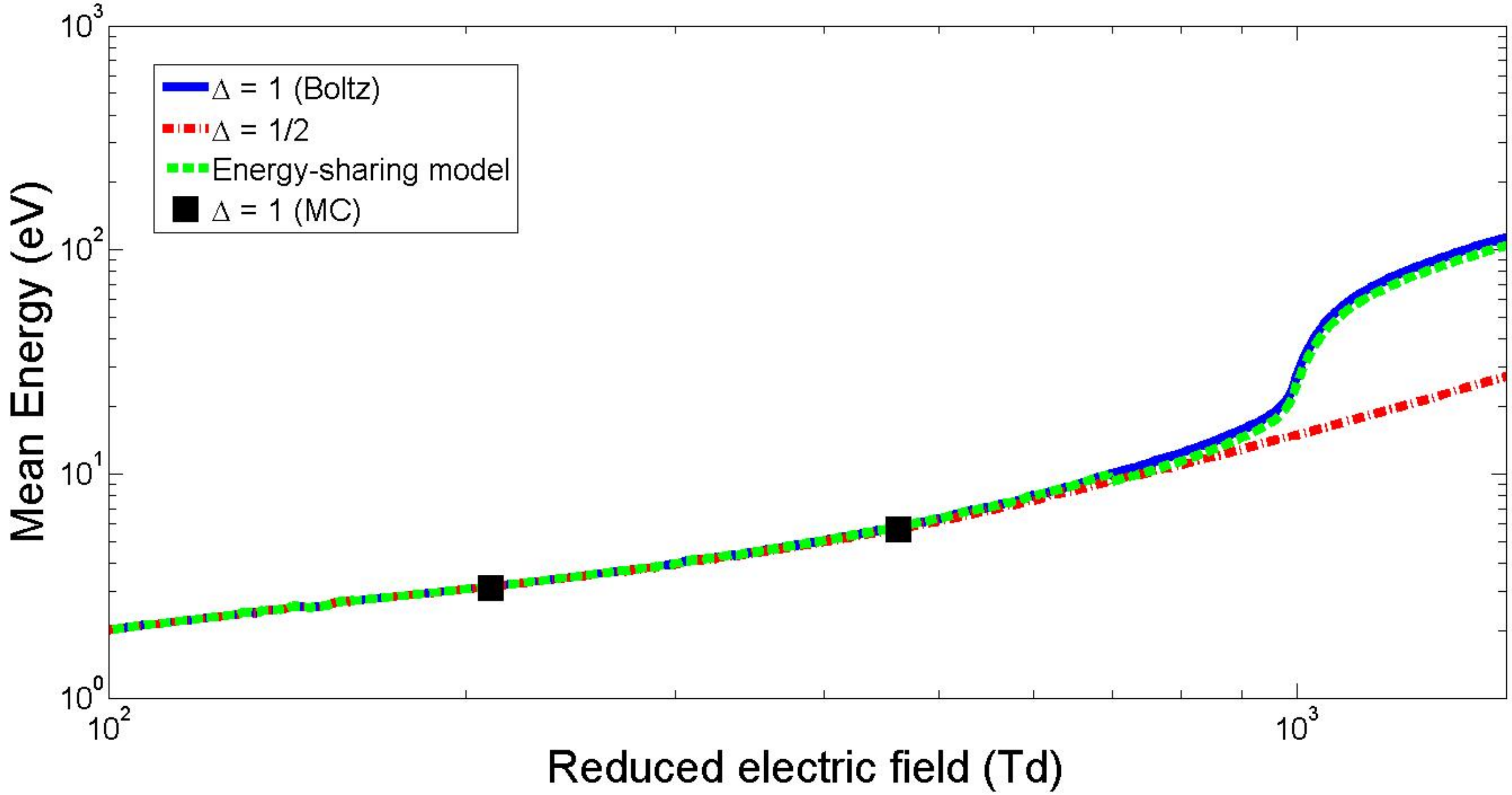
HELIUM PAIR-CORRELATION AND SCREENING

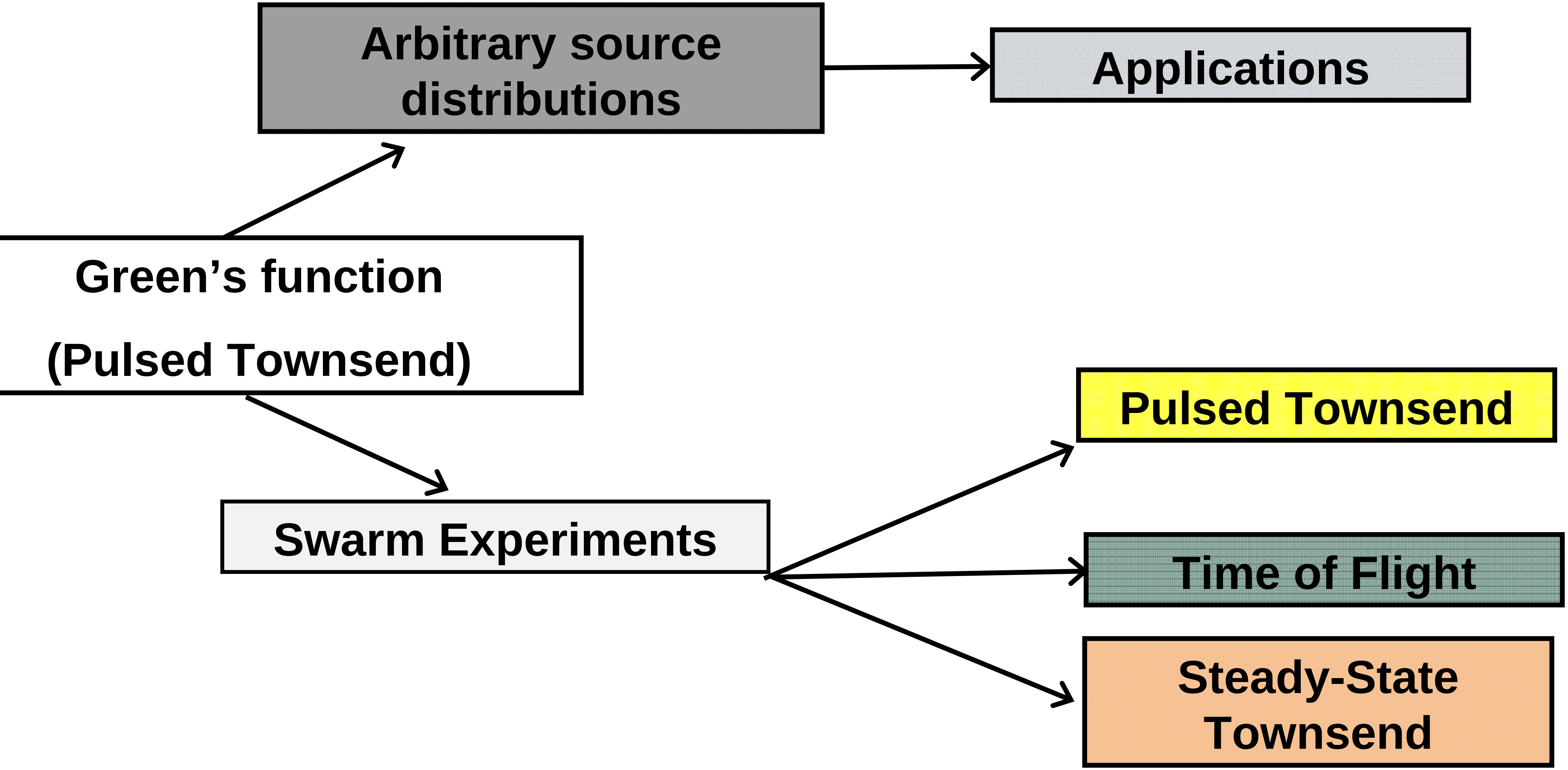






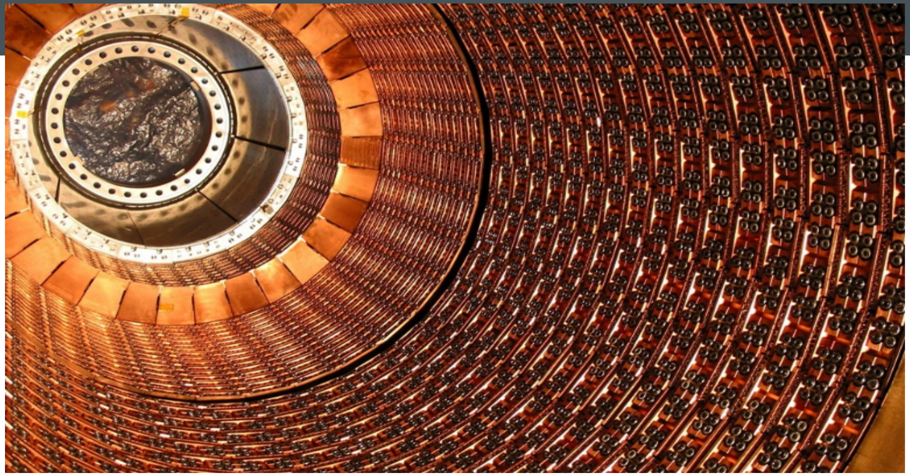
Δ = 1 (Boltz)
Δ = 1/2
Energy-sharing model
Δ = 1 (MC)
Mean Energy (eV)
Reduced electric field (Td)

ltzmann equation Green's function



ArTPC:

- *Neutrino detection*
- *Ionized electrons drift through liquid Ar*
- *Low field, low-energy regime*



$$/n_0 = 2.5 \times 10^{-3}\ Td$$
$$m_0 = 39.948\ amu$$
$$T_0 = 85\ K$$

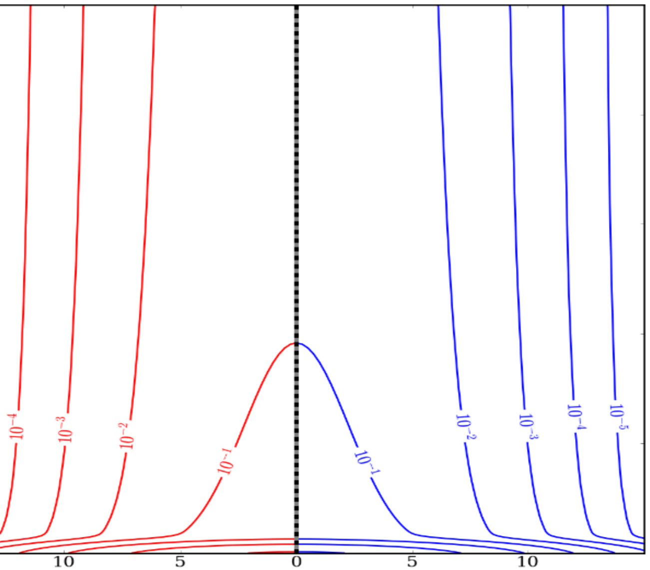
stribution function and transport properties:

$$f(U,z,t) = \sum_{l=0}^{\infty} f_l(U,z,t) P_l(\cos\chi) \longrightarrow$$

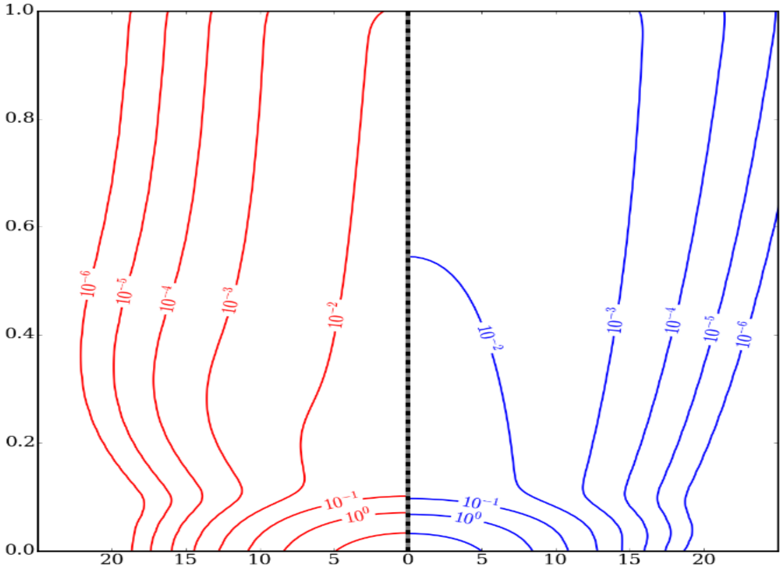
$$n(z,t) \propto \int dU\ U^{\frac{1}{2}} f_0(U,z,t)$$
$$n(z,t)W(z,t) \propto \int dU\ U f_1(U,z,t)$$

F_0 CONTOURS, NUMBER DENSITY

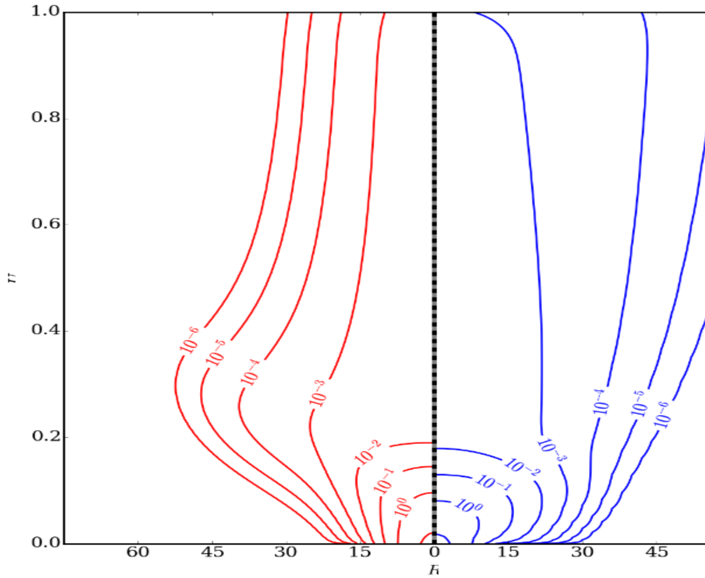
*=1

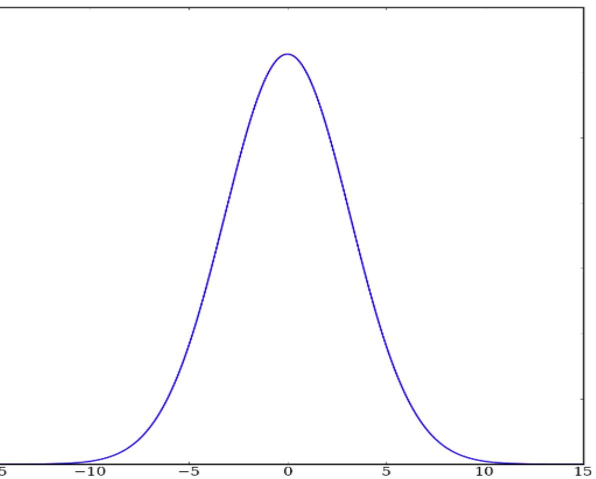


n_0t^*=20

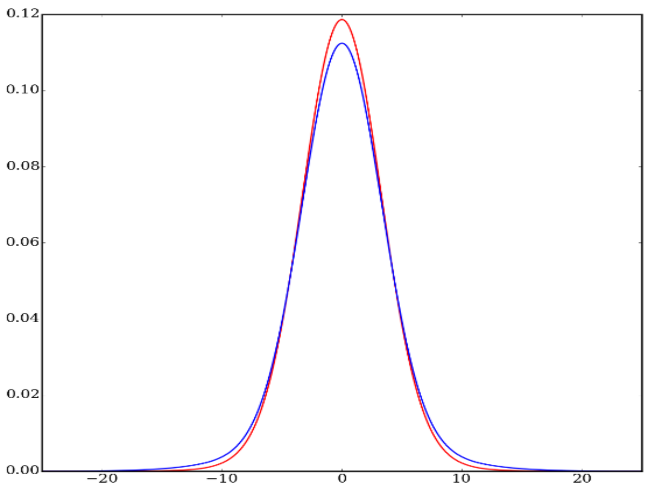


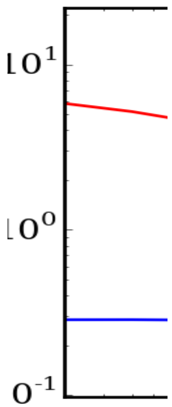
n_0t^*=100

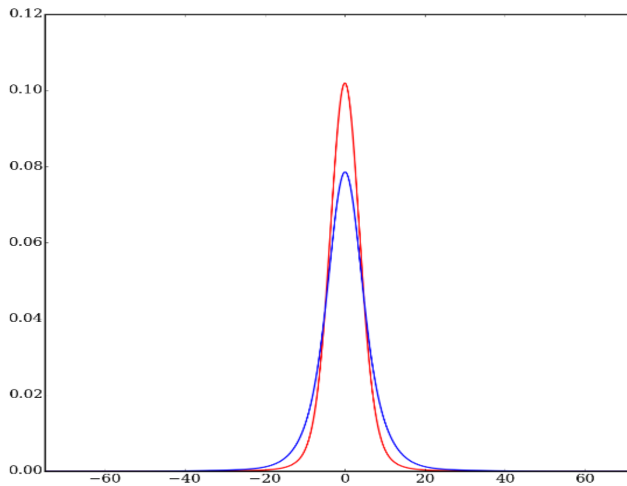




$z, t)$

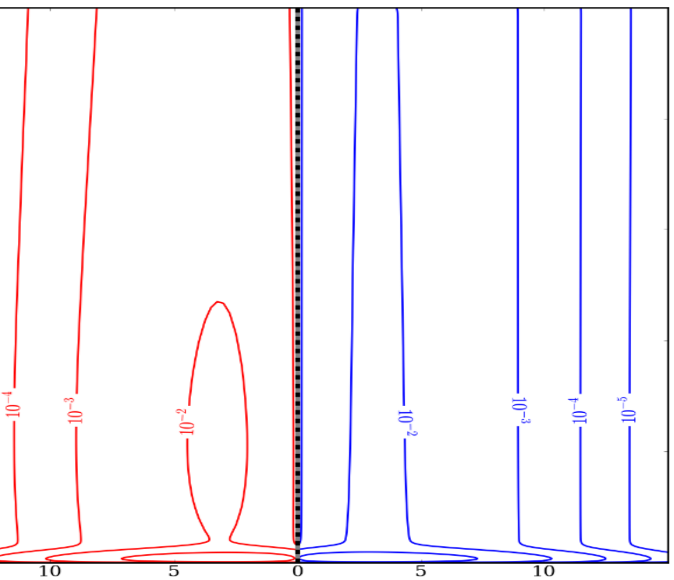




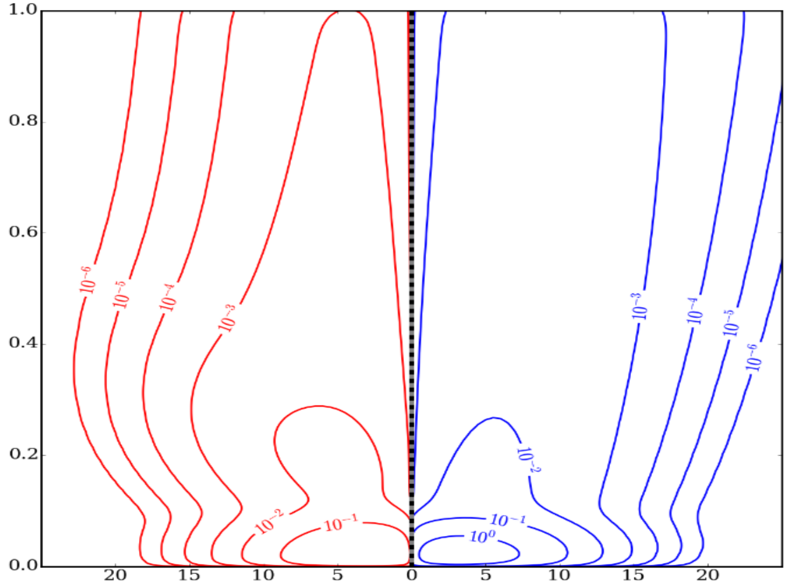


F_I CONTOURS, FLUX

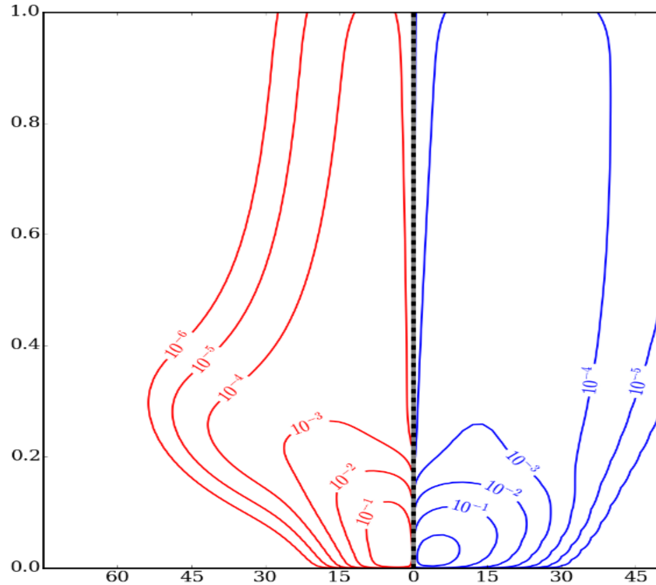
*=1

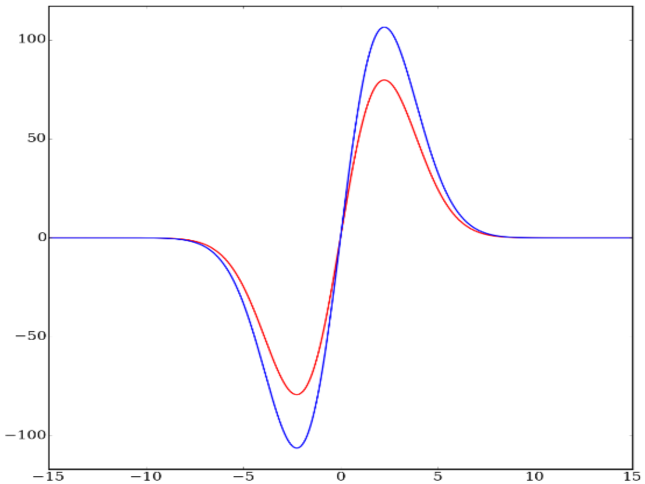


$n_0t^*=20$



$n_0t^*=100$





(U,z,t)