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Optimization of Atomic Beam Sources for Polarization Experiments

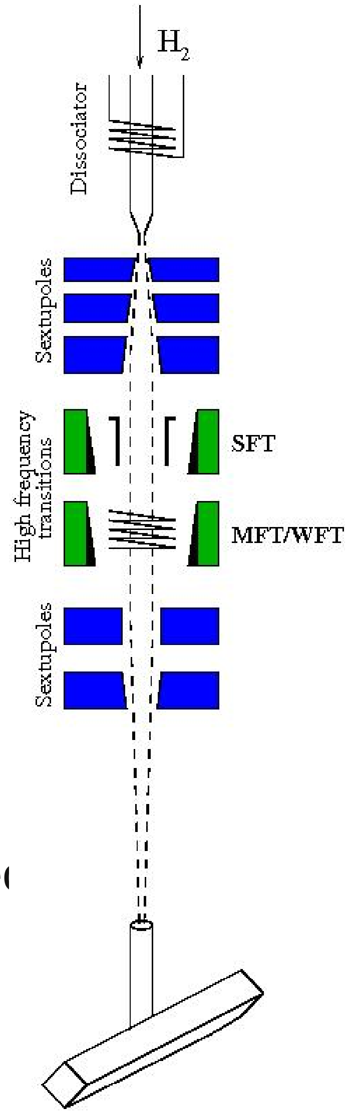
August 9, 2012 | Martin Gaisser

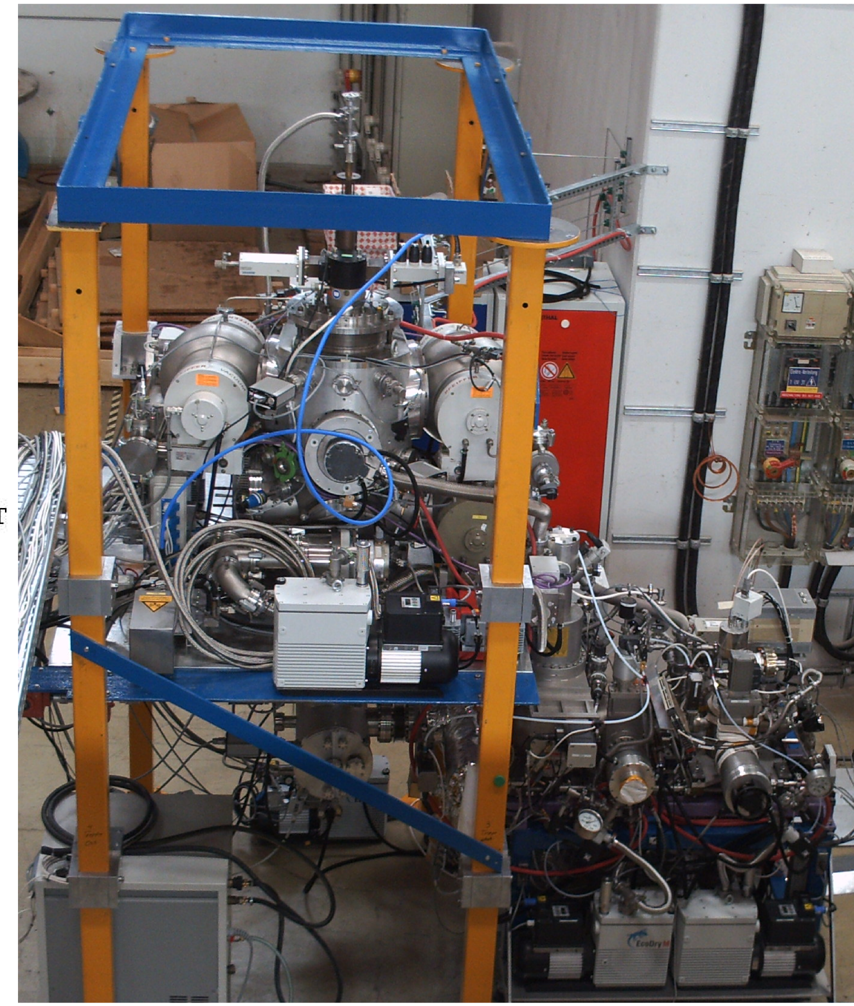
Motivation

Many nuclear reactions depend on the relative spin orientation of the reaction partners

Experimental requirements:
- High target density
- High polarization

Problems:
- Understanding all occuring effe
- Increasing target density





Atomic Beam Source with polarimeter

Hyperfine Structure of Hydrogen

Magnetic moment associated with spin:

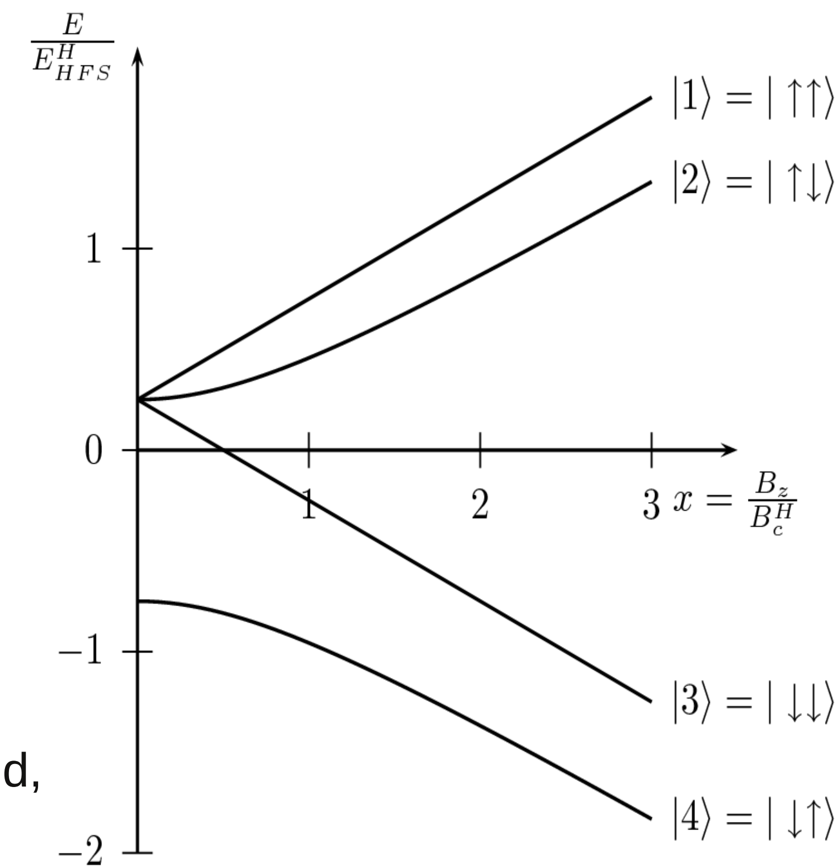
$$\vec{\mu} = g \frac{q}{2m} \vec{s}, \qquad g_e \approx 2.0, \qquad g_p \approx 5.59$$

$$\rightarrow \quad \mu_e \approx 658 * \mu_p$$

Weak external field: spins couple together

Strong external field: spins couple independently to external field

S-orbital splits into 4 states in an external field, each with its own energy level



$E^H_{HFS}/h = 1420.4\,MHz$
$B^H_c = 50.7\,mT$

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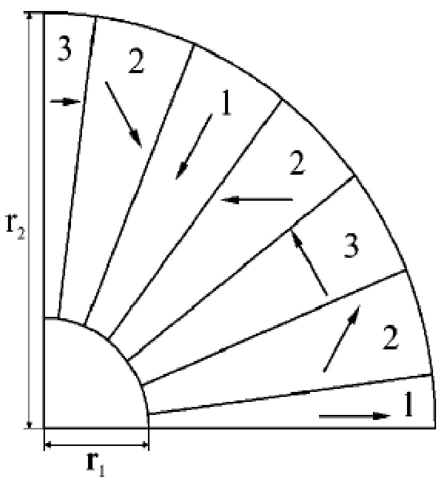
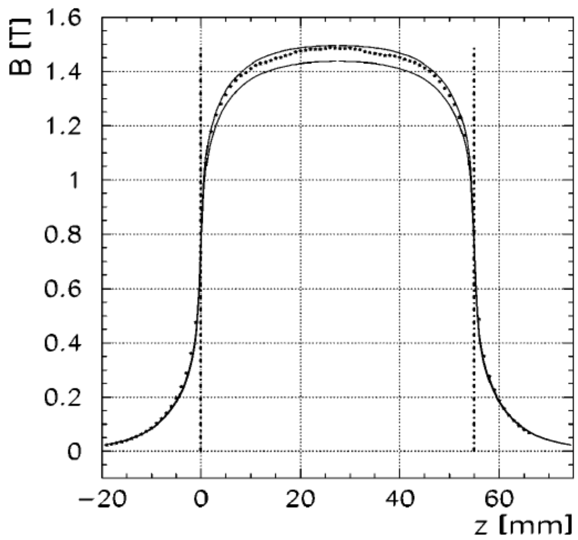
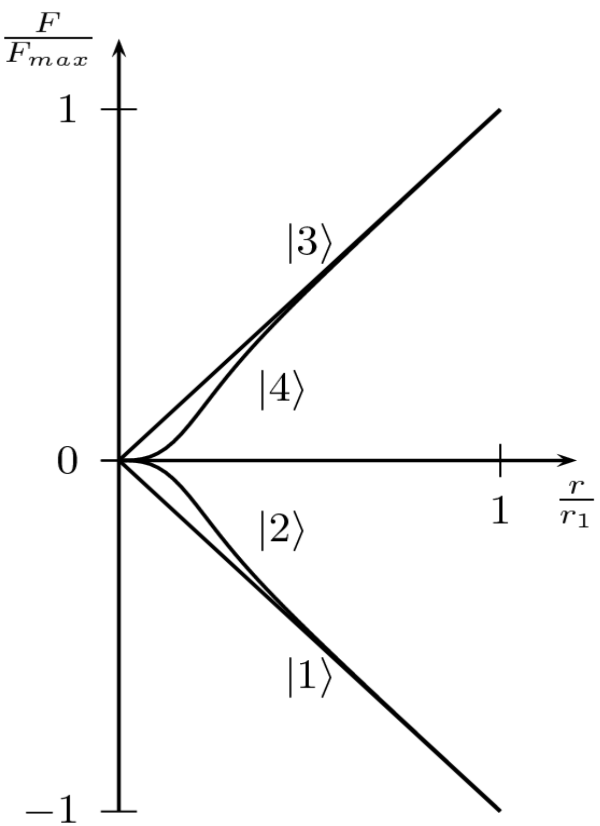
Sextupole Magnets



Segmented magnet design



B-Field along axis @ r = r_1



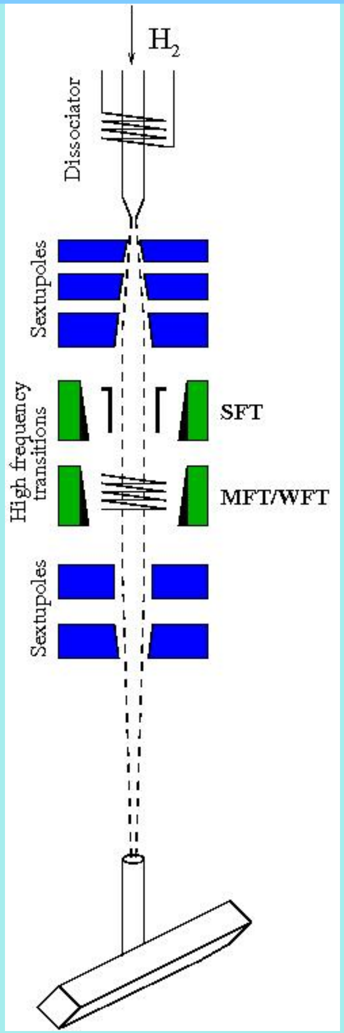
$$B = B_0 \left(\frac{r}{r_1}\right)^2$$

$\rightarrow$ Potential of harmonic oscillator

$$B_0 = 0.98\,T$$
$$r_1 = 11.4\,mm$$

Schematic view of an Atomic Beam Source (ABS)

Sketch of an ABS



$|1\rangle, |2\rangle, |3\rangle, |4\rangle$

$|1\rangle, |2\rangle \Rightarrow\Leftarrow$

$|3\rangle, |4\rangle \Leftarrow\Rightarrow$

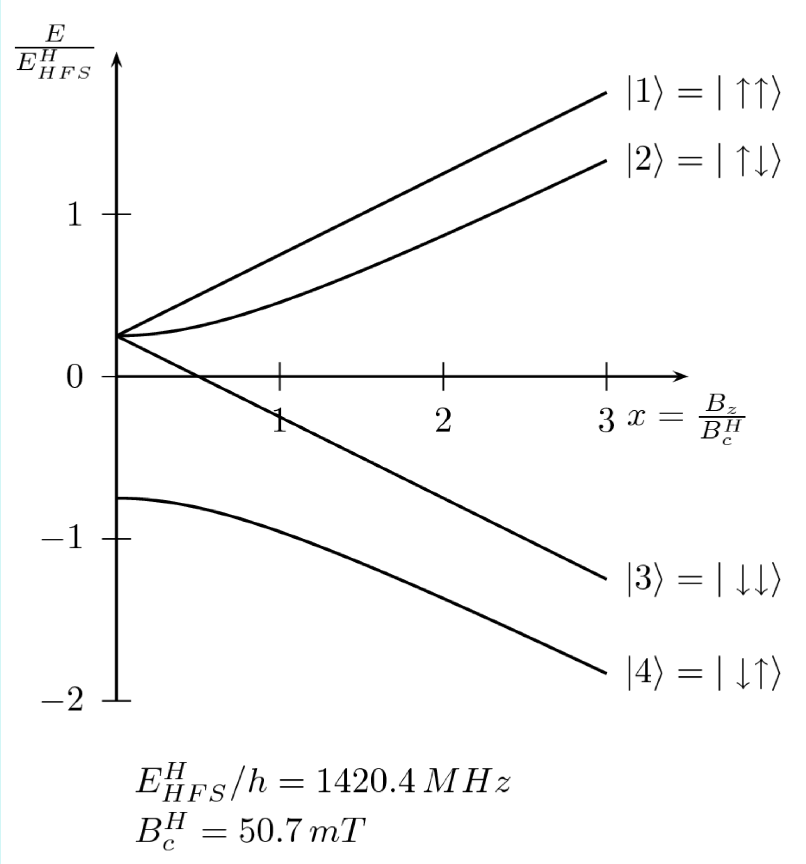
$|2\rangle \Rightarrow |3\rangle$

$|1\rangle \Rightarrow\Leftarrow$

$|3\rangle \Leftarrow\Rightarrow$

$|1\rangle$

Hyperfinestructure



Simulation of gas flows

Standard way: Solve Navier-Stokes Equation

But: density too low → continuum approximation doesn't hold
→ Navier-Stokes Equation not valid!

Other possibility: Simulate all molecules

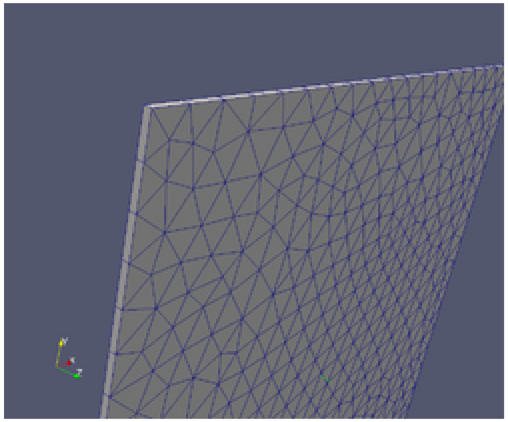
But: Far too many particles, impossible to simulate!

Solution: Use statistical properties to simulate some particles
⇒ Direct Simulation Monte Carlo (DSMC)

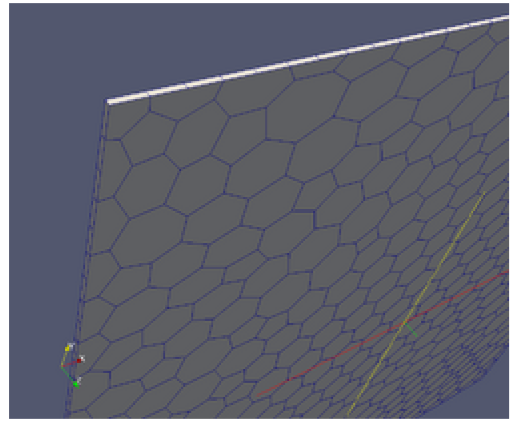
Idea:

- Translation and collisions of particles are independent on short timescales
- Each simulated particle represents e.g. 10^{10} real particles

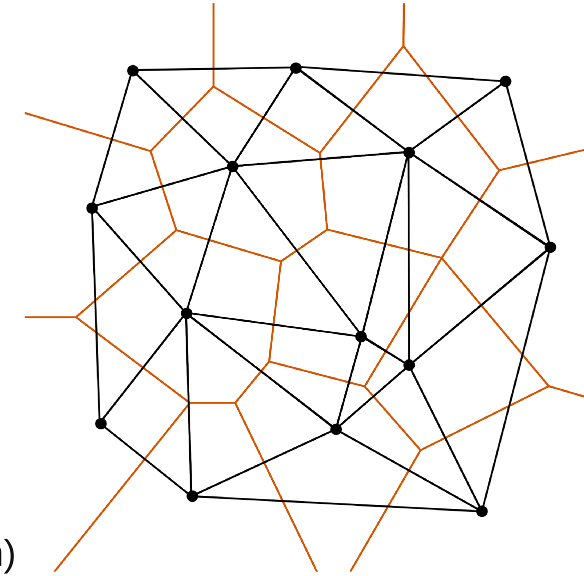
DSMC needs a mesh!

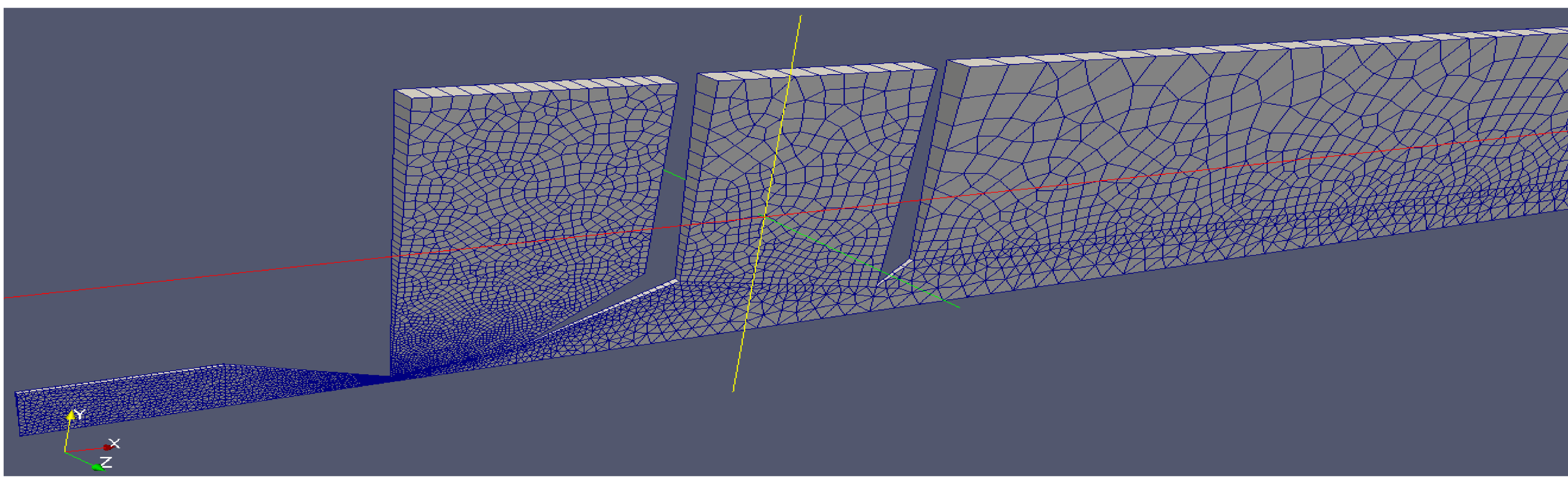


Delauny-Triangulation



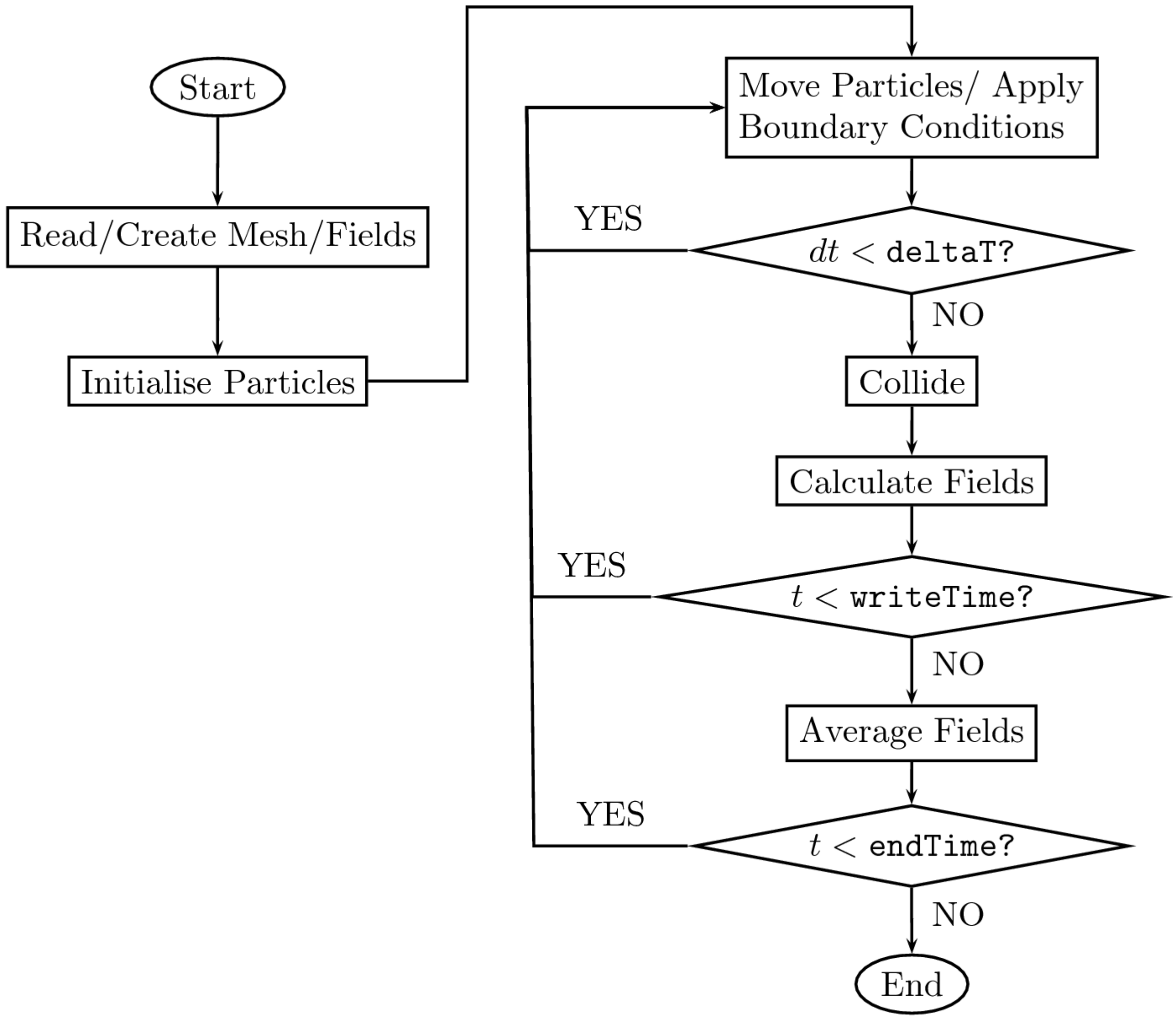
Voronoi-Mesh (dual of Delauny Mesh)



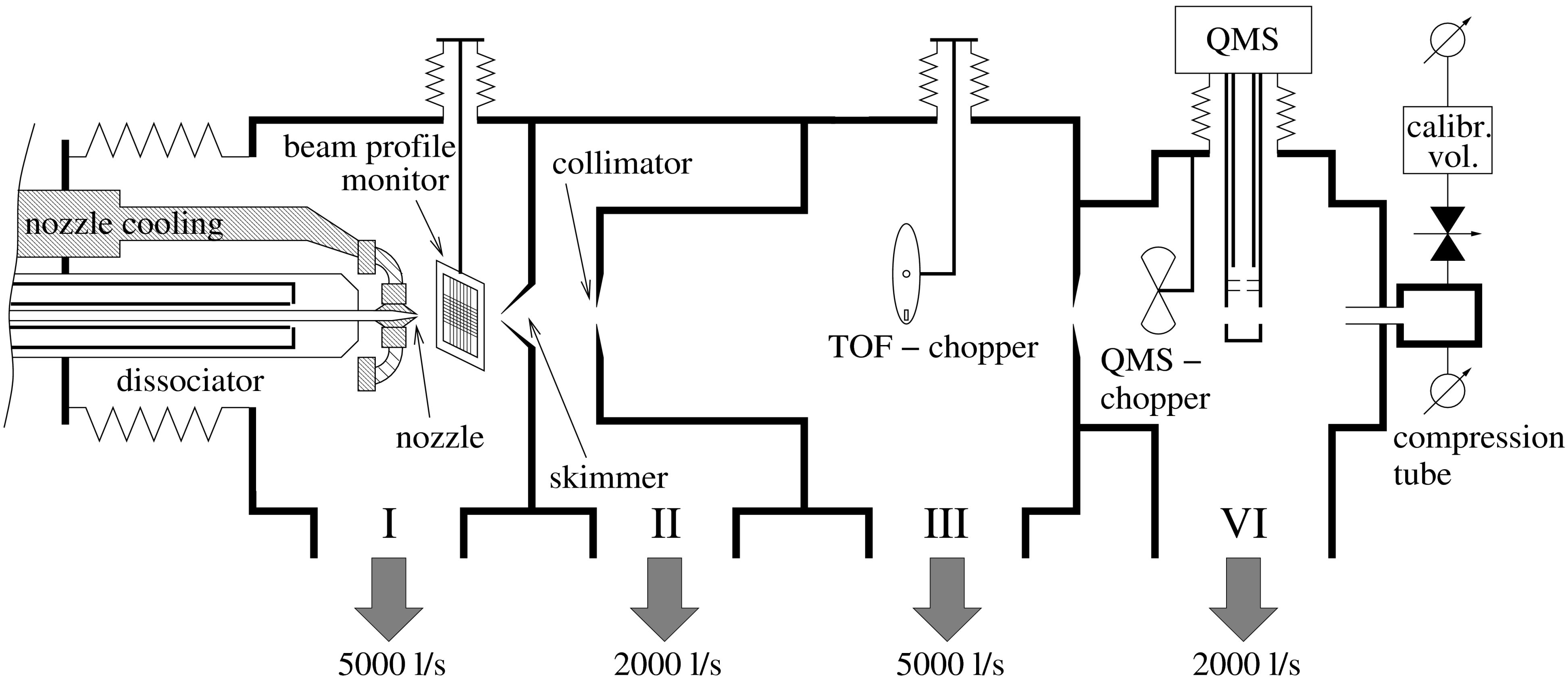


Mix of triangles and quadrangels, cell size should be of the order of the mean free path length of the particles

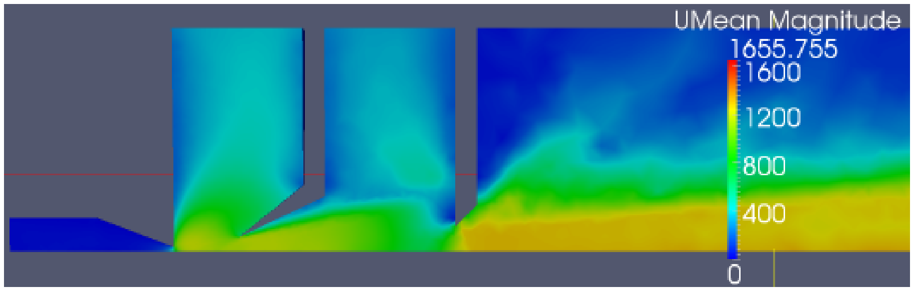
DSMC flow chart



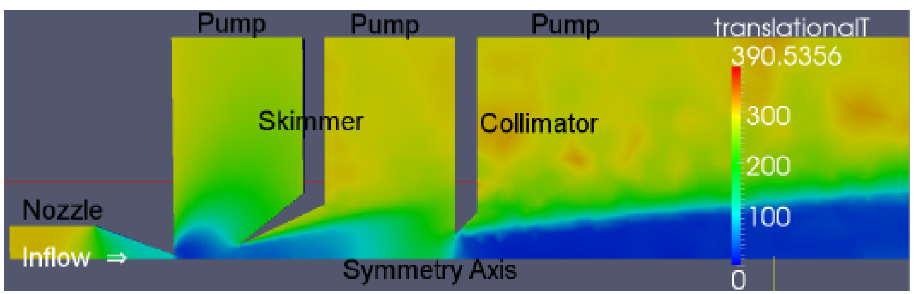
The Test Stand



Example: Simulation of Test Stand



Magnitude of velocity field



Temperature distribution

Pressure distribution

Parameters

Species: H_2

T_{inflow}: 300 K

T_{nozzle}: 100 K

Q: 1 mbarl/s

	measured	simulated
U [m/s]	1274 ± 8.4	1290
T [K]	19.03 ± 1.11	16.5
p_1 [mbar]	$2.1 \cdot 10^{-4}$	$3.4 \cdot 10^{-4}$
p_2 [mbar]	$1.8 \cdot 10^{-5}$	$2.7 \cdot 10^{-5}$
p_3 [mbar]	$7.0 \cdot 10^{-7}$	$8.0 \cdot 10^{-7}$
p_4 [mbar]	$1.7 \cdot 10^{-7}$	$1.7 \cdot 10^{-7}$

Program used for Simulation: OpenFOAM

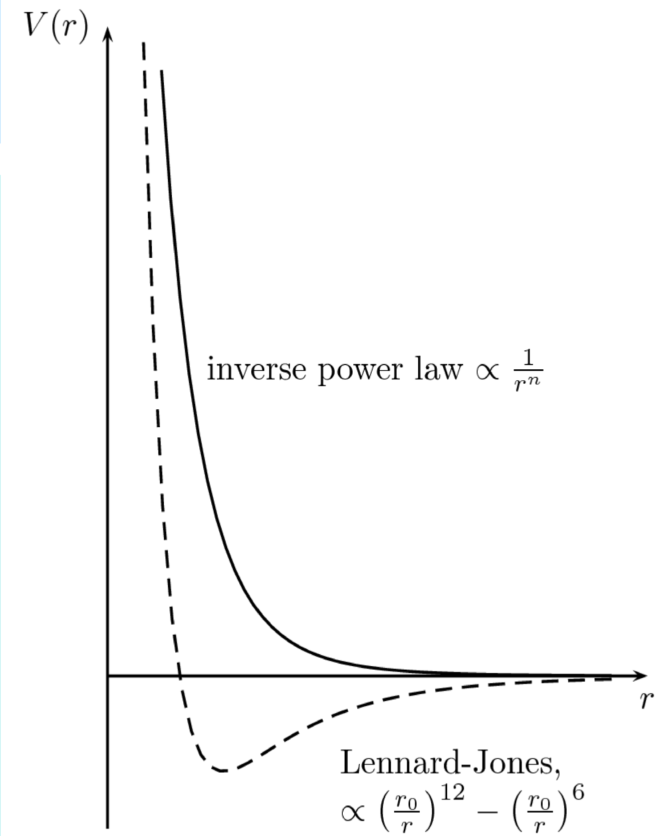
OpenFoam:

- Open source software
- Available at: http://www.openfoam.org
- Programming language: C++
- Originally a solver for partial differential equations, with additional features using the same common infrastructure
- Plenty of pre- and postprocessing capabilities
- Possibility of parallel computing (domain decomposition)
- Interface with ParaView for visualization
- Intended for user programmed extensions

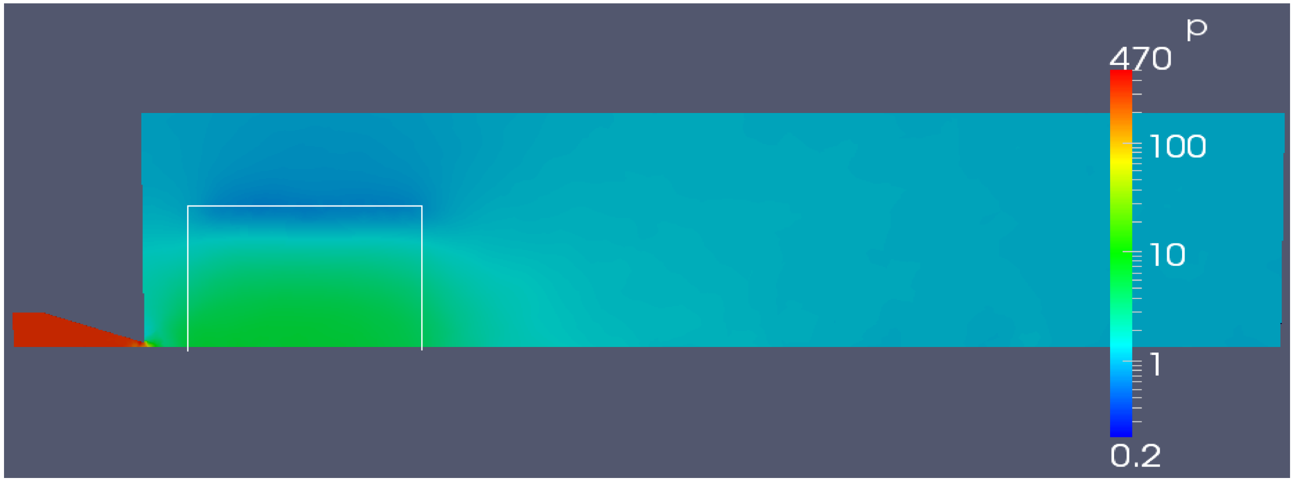
Extensions to OpenFOAM 1.7.1

- Pressure driven flows, implemented by Marta Lazzarin, now available from http://www.physimmasters.com

- New binary collision model based on Lennard-Jones Potential
- Particles with spin
- Fields of hyperfine states for visualization and calculation of polarization
- Generic interface for magnetic fields acting on particles with spin
- Particles count the number of wall collisions, useful for determination of recombination at surfaces



Simulations with magnetic field



Pressure distribution for state |2⟩

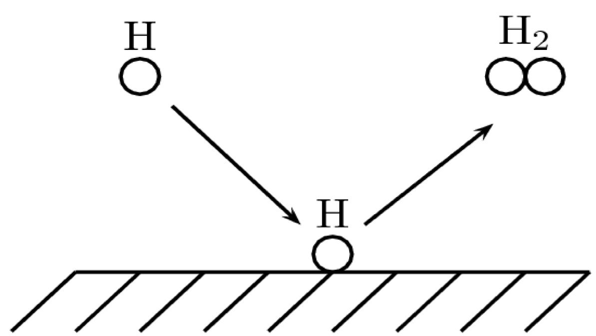
Pressure distribution for state |3⟩

Parameters:

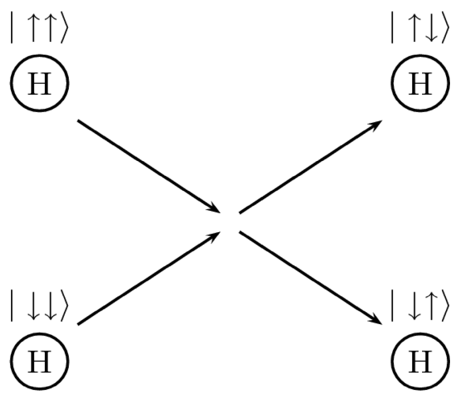
Species:	H
T_{nozzle}:	100 K
Q:	≈ 20 mbarl/s
B_0:	1500 T

To Do List

- Compare simulations with measurements
- Include hfs-transition units
- Include recombination on the walls
- Include spin exchange collisions
- Check influence of fringe fields
- Prepare simulation to run with an optimization algorithm
- Documentation



Recombination on the wall



Spin exchange collision