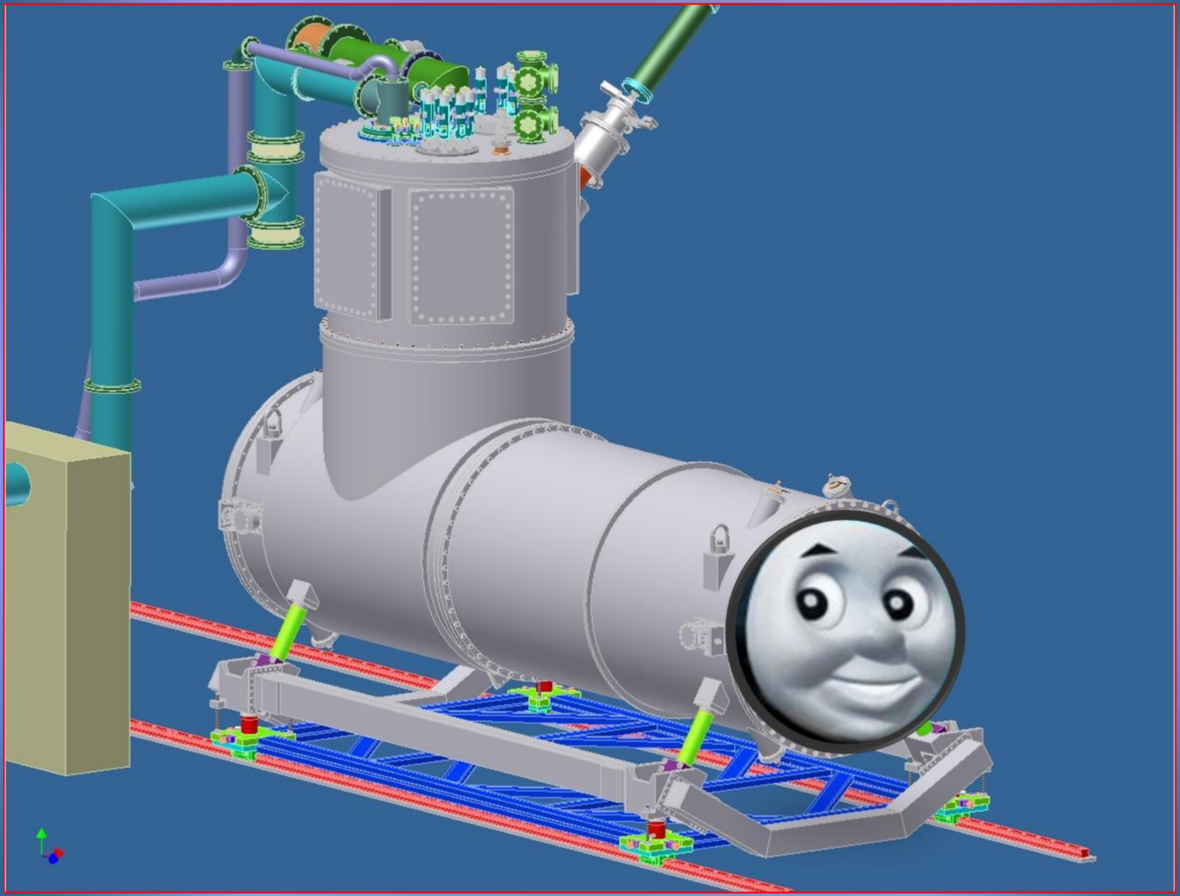
ABS for NEDM experiment at SNS



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Motivation

There are three basic symmetries:

Space (P-symmetry) - left = right

Charge (C-symmetry) - matter = antimatter

Time (T-symmetry) - time reversal

CPT symmetry is always conserved. Violation of CPT symmetry contradicts to causality. Therefore T-symmetry = CP-symmetry

P-symmetry is conserved in electromagnetic, gravitational and strong interaction. It is broken in weak interaction.

Motivation

CP-symmetry violation is an extremely important phenomenon. CP violation during the Big Bang is responsible for the imbalance of the matter and antimatter in the Universe.

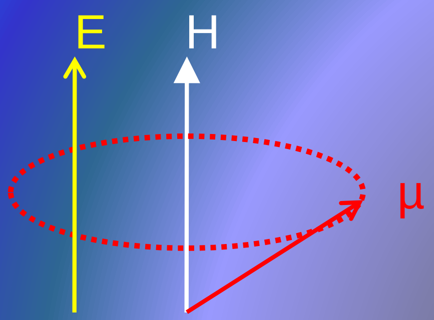
Experimentally, CP-symmetry violation was found only in K-mesons and B-mesons decay so far.

The energy of fermion (spin=1/2) with Electric Dipole Moment = D in the electric field is equal to : $E_n = D\vec{\sigma} \cdot \vec{E}$

This expression is odd under T (and P), so if D≠0, it is a unique signature of CP violation.

It applies to EDM of electron, proton, neutron, diamagnetic atoms.

Neutron EDM



Spin precession in the magnetic field:
Frequency hv=2μB

Additi[illegible]l electric [illegible]d:
Frequency hv=2μB ± 2DE

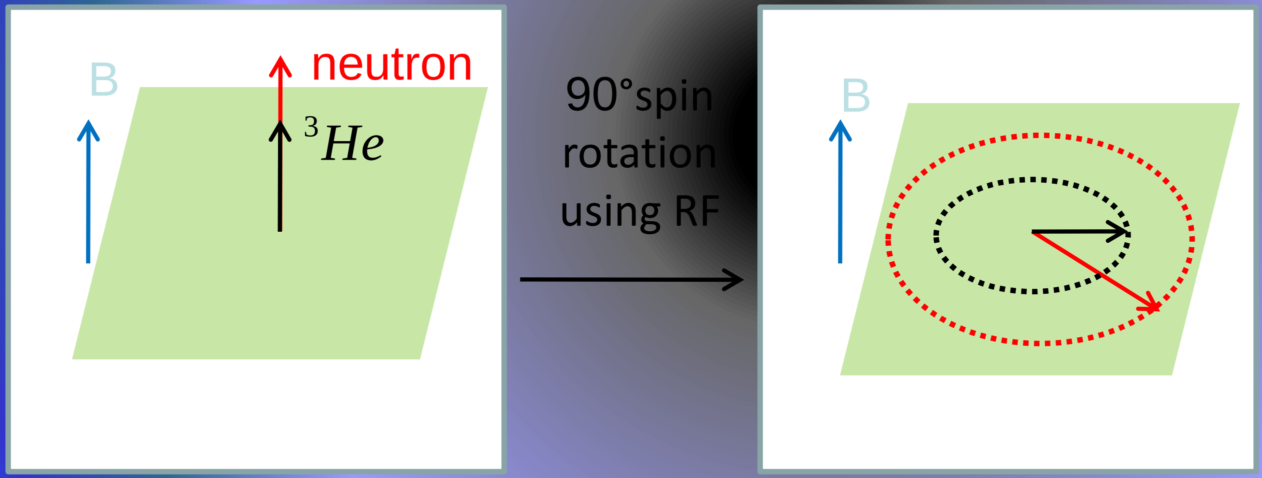
B=1 mG, E=50 kV/cm
v=2.9 Hz, Δv= .19 μHz
Δv /v= $6.6 \cdot 10^{-8}$

^{3}He magnetometer

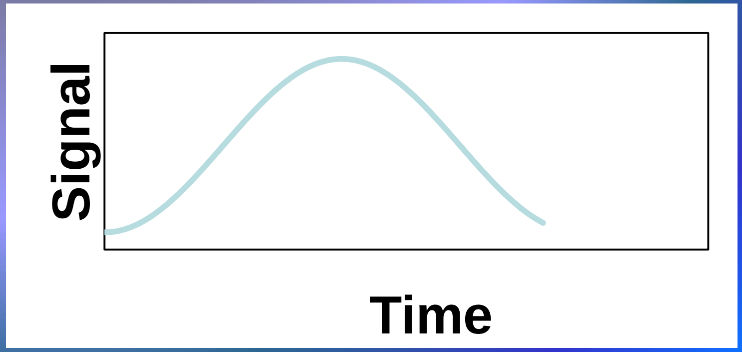
The cross-section for neutron absorption by ^{3}He is highly spin dependent:

$$\sigma = \sigma_0 (1 - a \cdot \cos(\varphi)),$$

where $a \approx 1$, and φ – angle between neutron and ^{3}He spins



The frequency of the signal is a beating frequency between neutron and ^{3}He spin precession.



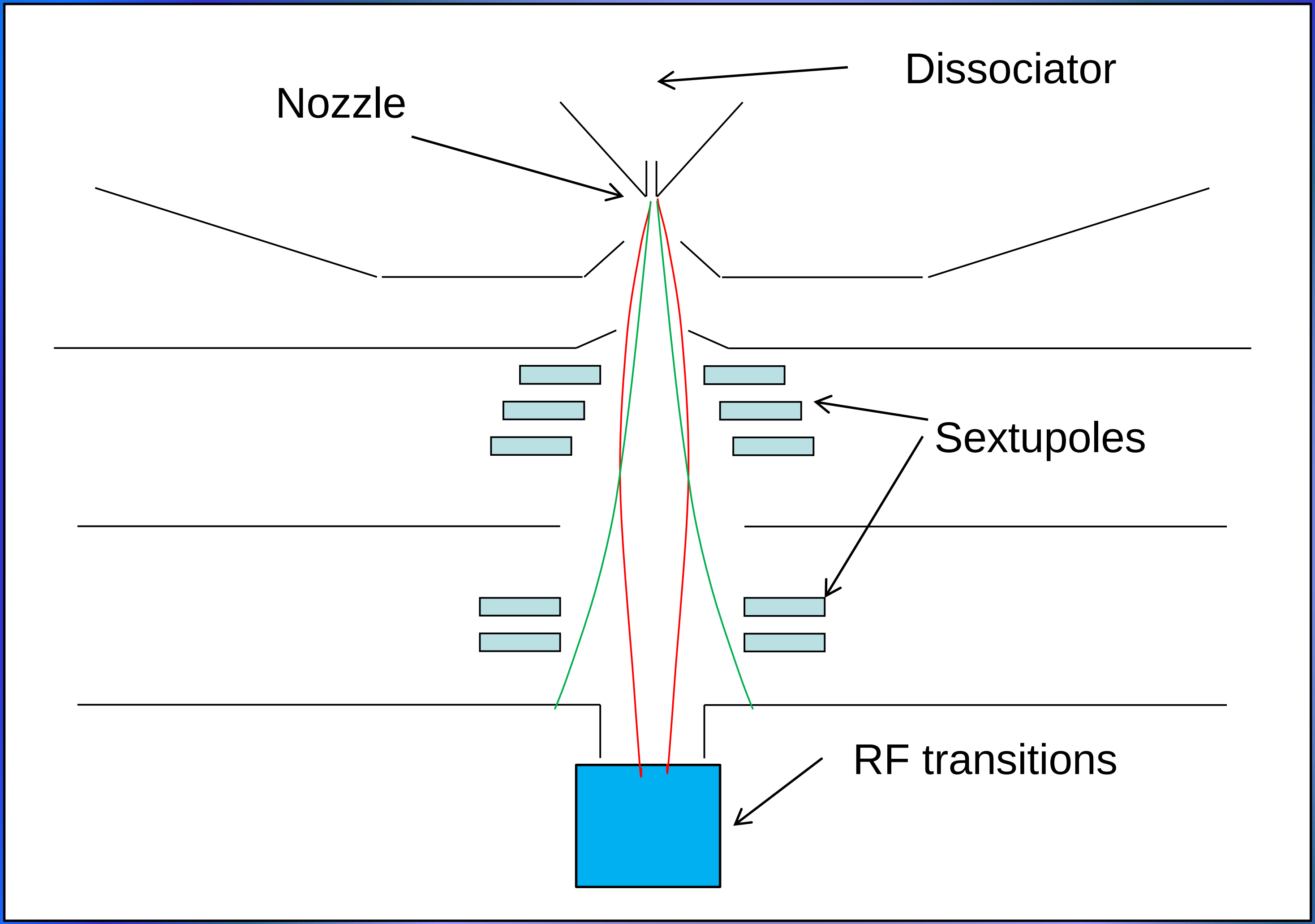
^{3}He magnetometer

- The detectors measure the beating frequency between neutron and He spin precession. The He spin precession is measured by SQUIDS; the difference gives the neutron spin precession.
- He atoms pass through the same magnetic field non-uniformities as neutrons do, that cancels the first order effects.
- Still, very high magnetic field uniformity (~.001) is required.
- The frequency shift on E-field reversal is measured.

Why ABS ?

- Only ABS provides polarization close to 100 %.
- Although ABS intensity is low, it is sufficient for this experiment.
- ABS produces a beam of cold polarized atoms. These atoms are injected in liquid ^4He at temperature ~ 400 mK and very uniform magnetic field of ~100 mG. The polarization stays high for tens of minutes.

Hydrogen (Deuterium) ABS

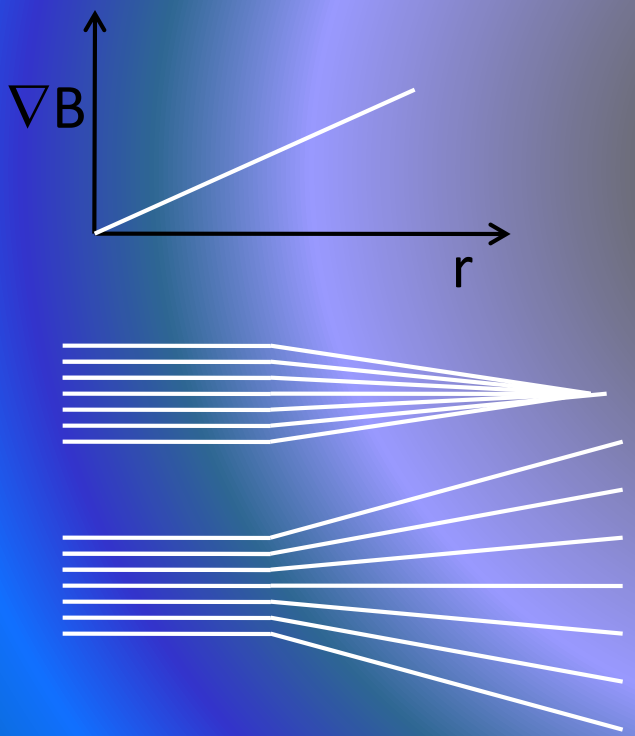


Hydrogen ABS uses atomic magnetic moment. Helium ABS has to use nuclear moment, and it is 1000 times smaller.

Sextupole vs Quadrupole

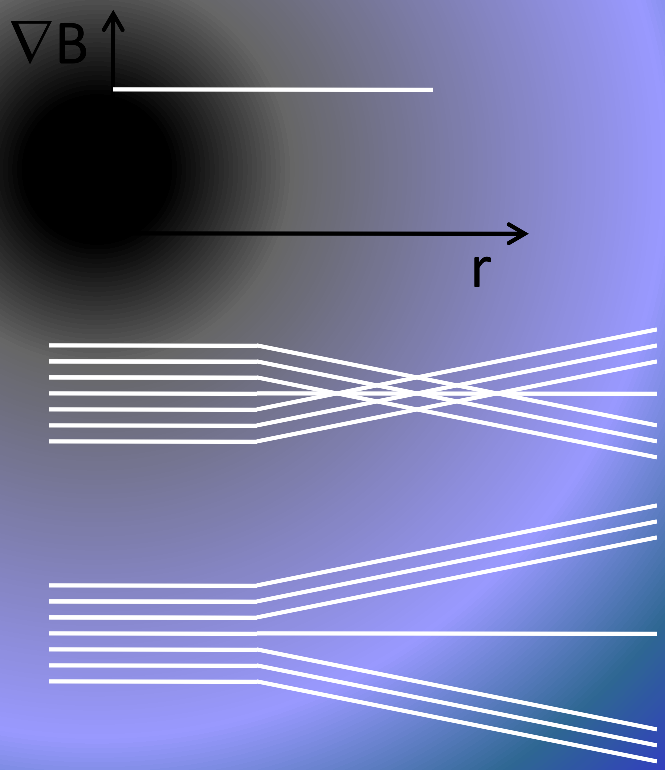
The force acting on a magnetic dipole $\vec{F} = \mu \cdot \vec{\nabla} B \quad \mu(H,D) \approx 1000 \cdot \mu(^3He)$

Sextupole



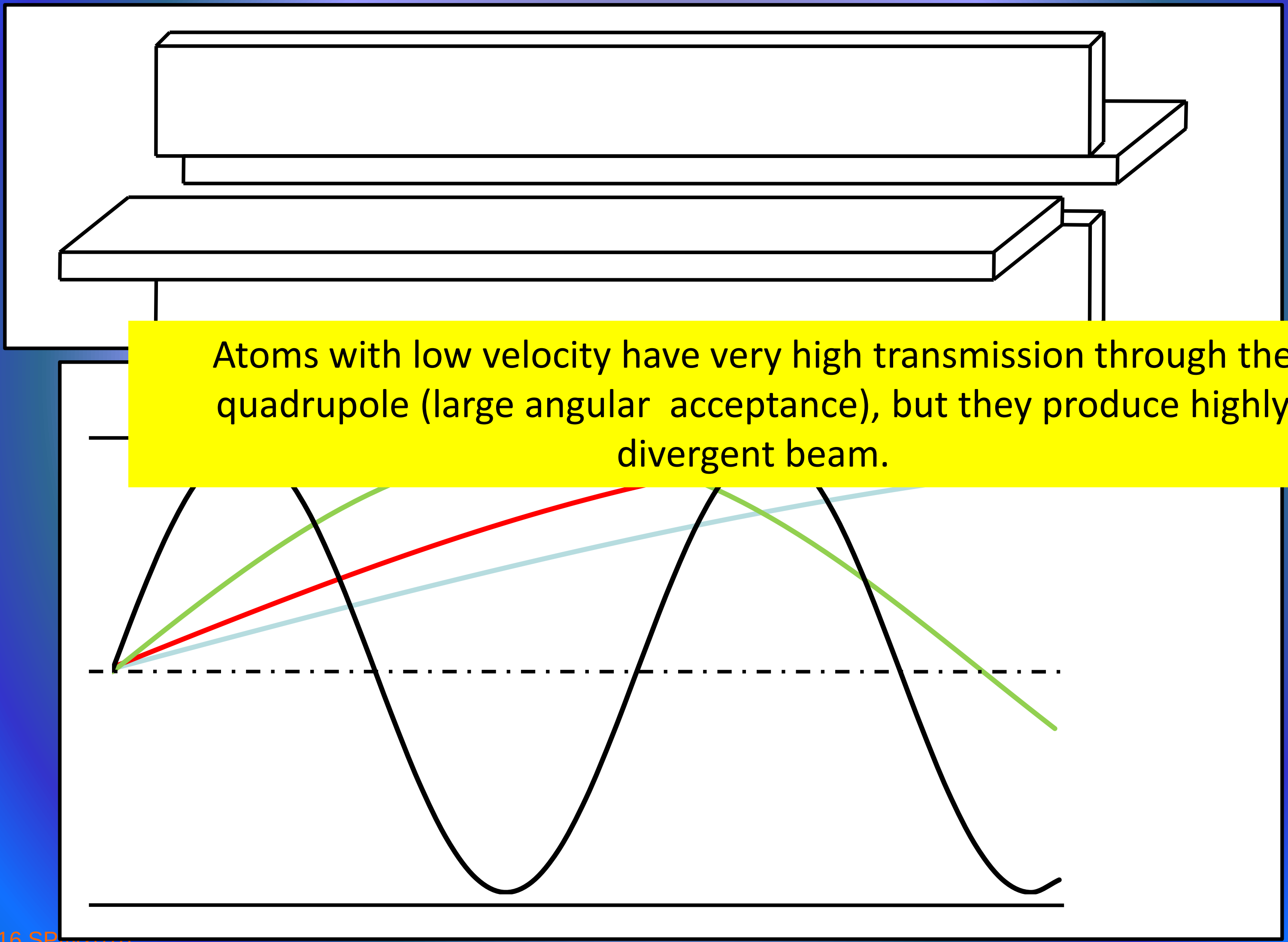
Good for H,D (large µ) - focusing

Quadrupole



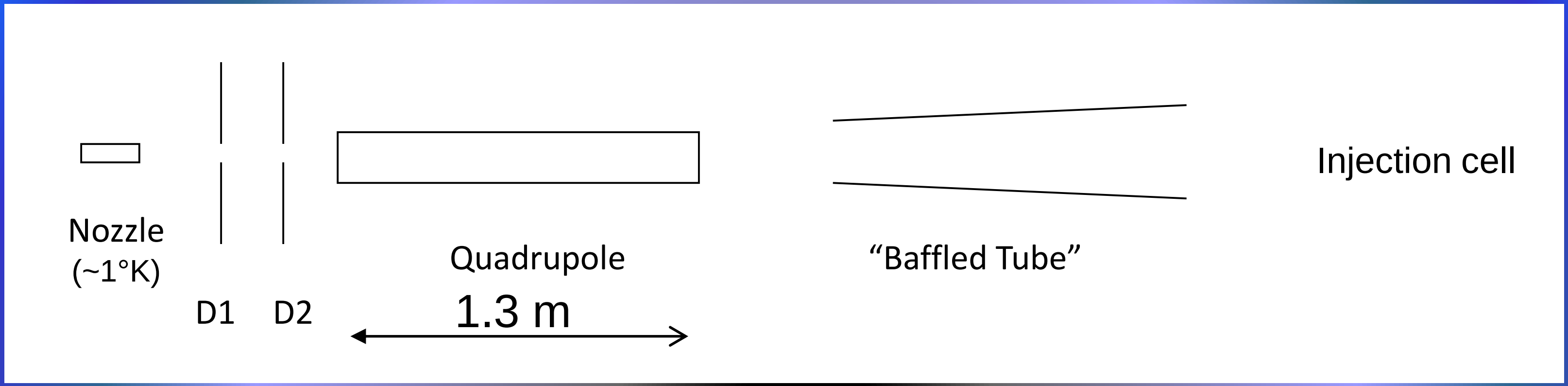
Good for He (small µ) –high polarization

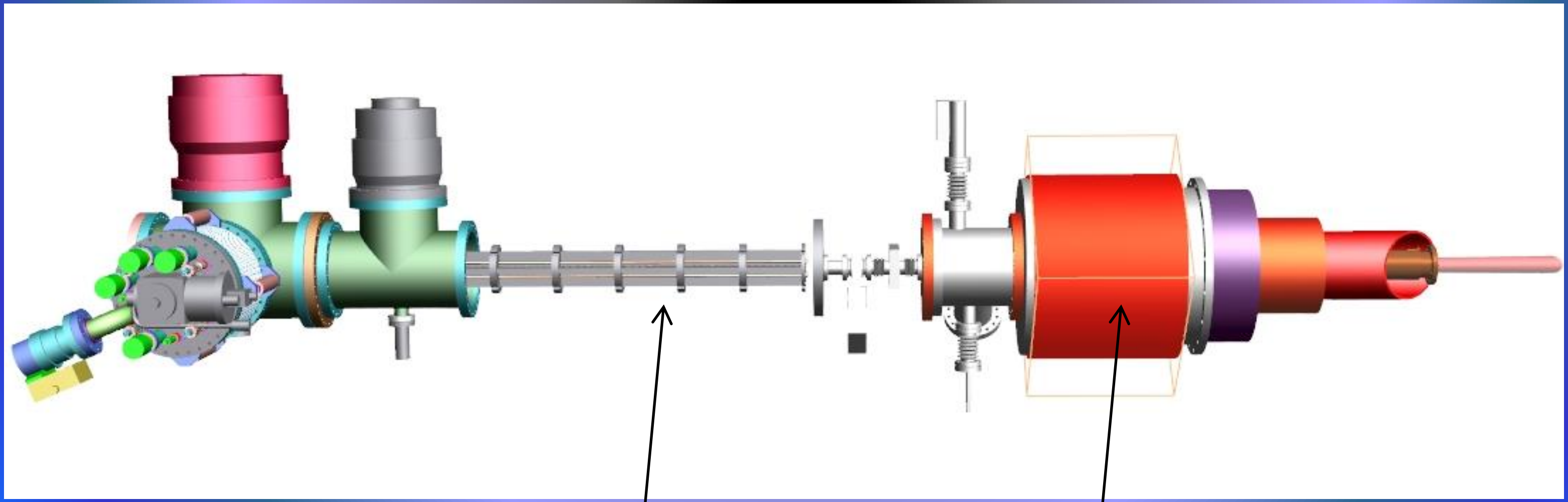
Quadrupole acceptance



Atoms with low velocity have very high transmission through the quadrupole (large angular acceptance), but they produce highly divergent beam.

Atomic Beam Source





Quadrupole

Magnetic coils

Atomic Beam Source

- Quadrupole is used to achieve high (>99%) degree of polarization. Sextupole has better optical properties, but gradient is too low near the axis.
- In order to have adiabatic transition from ~kG magnetic field in the quadrupole to ~100 mG field in the injection volume a complicated system of magnetic coils is used.
- Another system of coils provides adiabatic transition between the injection volume and measuring cells.
- The ABS intensity is about 10^{14} at/sec.

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Current status

- ABS was built in Los Alamos about 15 years ago (Steve Lamoreaux). Preliminary measurement confirmed that ABS works, but most of the measurements were indirect.
- Recently ABS was moved to MIT for evaluation and, perhaps, modification.
- We found that many parts (pu[illegible] cooling head and so on) are worn out and need to be replaced for a real experiment.
- We plan to measure directly beam intensity and divergency.

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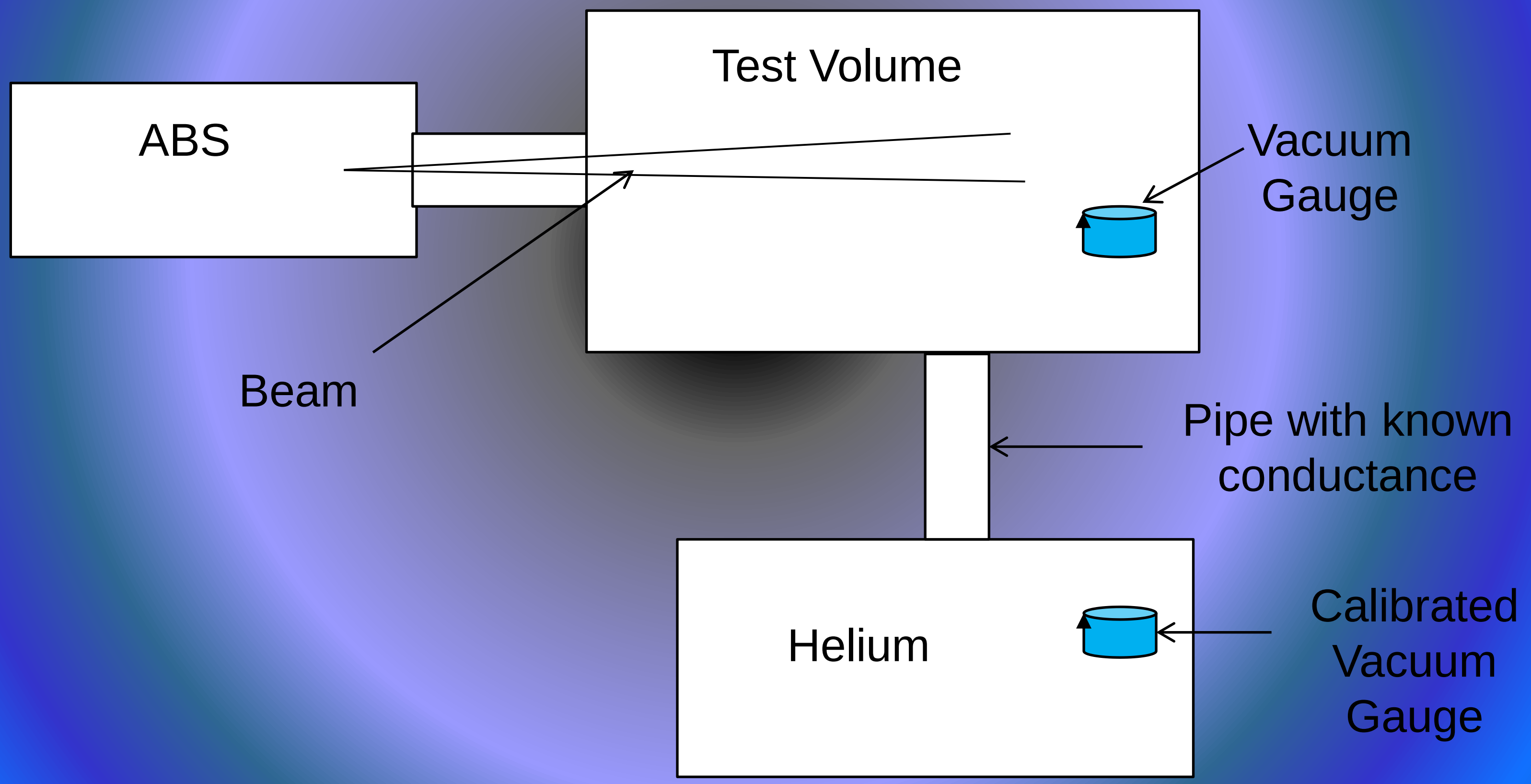
Direct intensity measurement



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Possible sources of depolarization

- Non-adiabatic transfer from the very high magnetic field in the quadrupole (~kG) to a very weak field in the injection volume (~100 mG)
- A complicated system of coils is used to provide adiabatic transition.
- Magnetic field non-uniformity in the collection volume
- Cosθ coil is used for high uniformity.
- Collisions with the walls during transport from ABS to injection volume.

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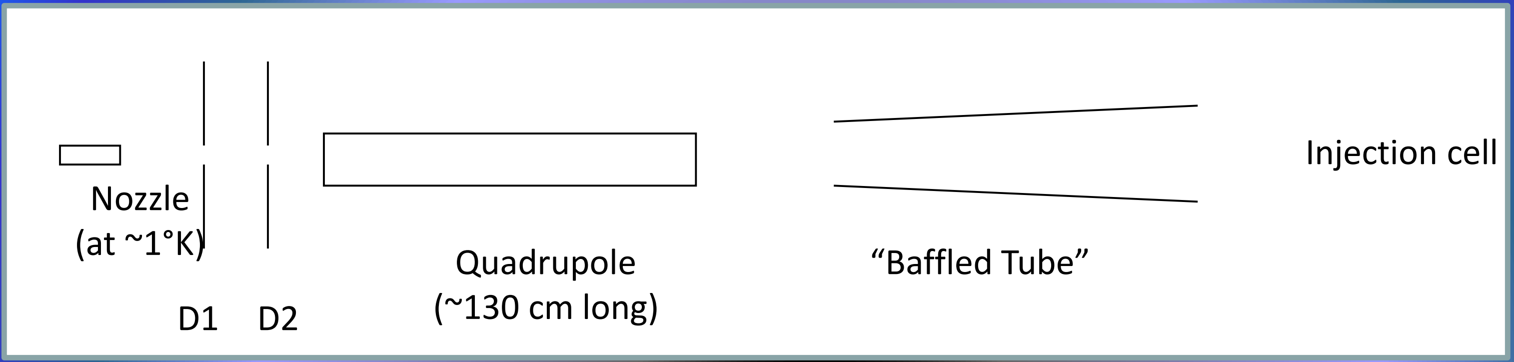
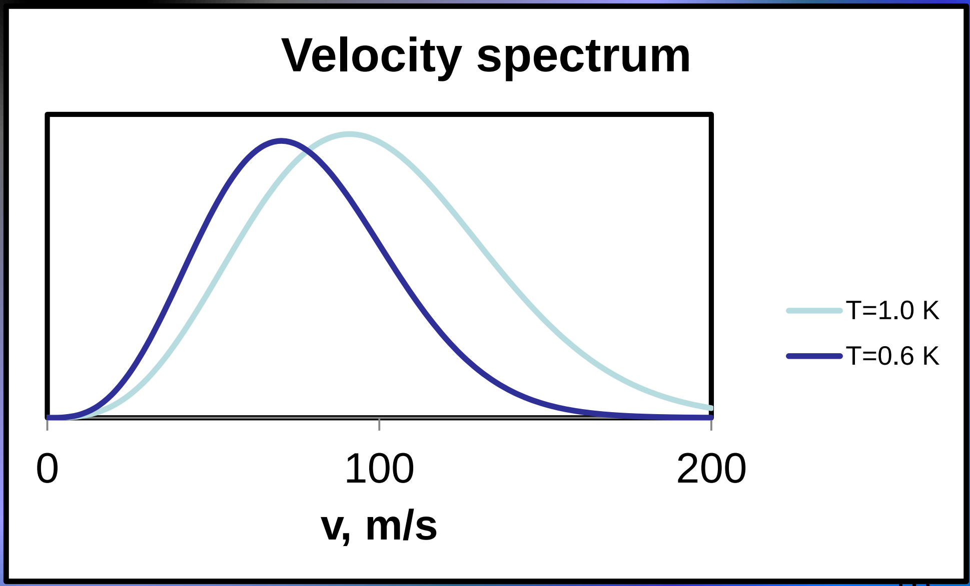
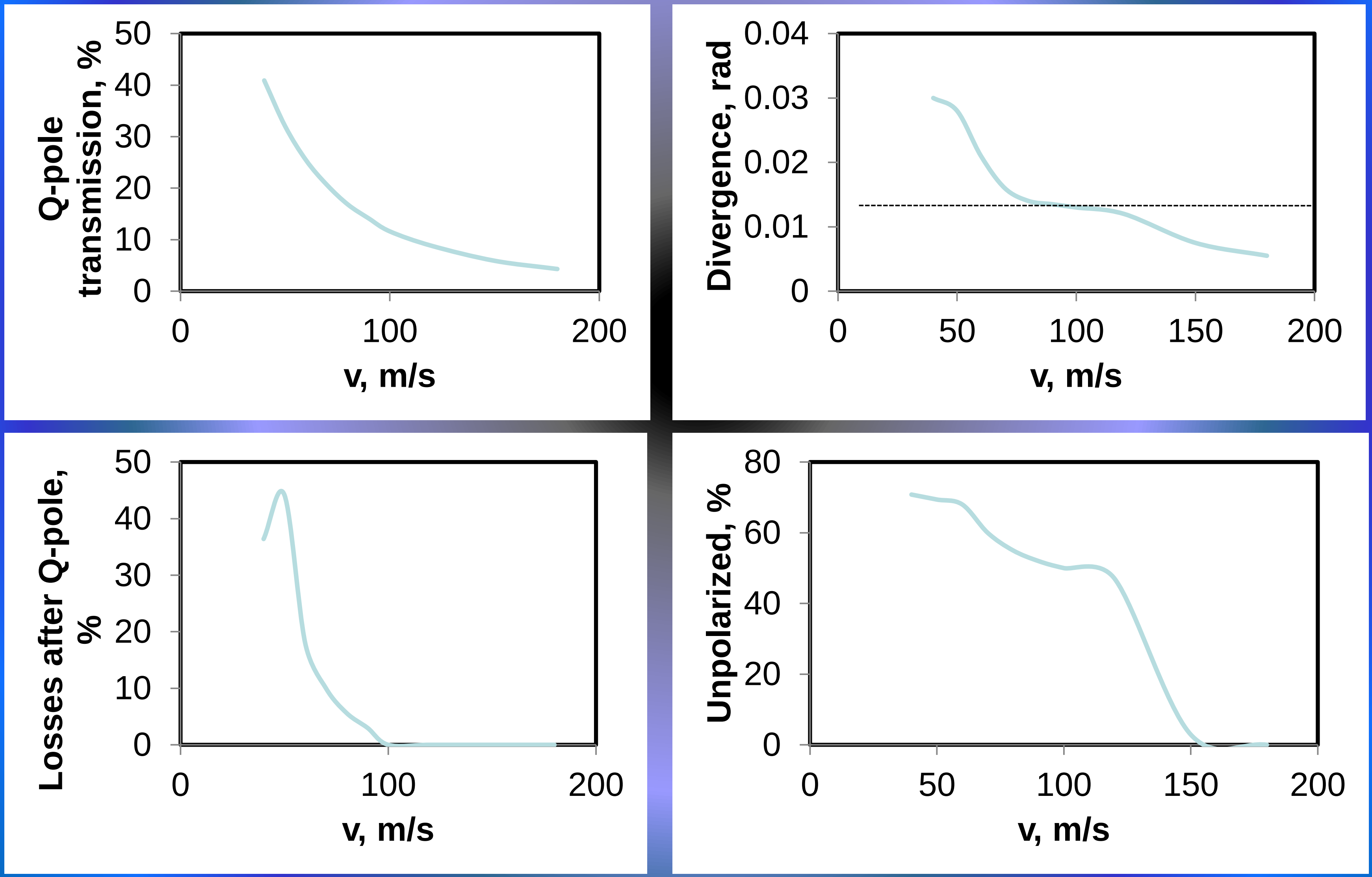
Beam divergence



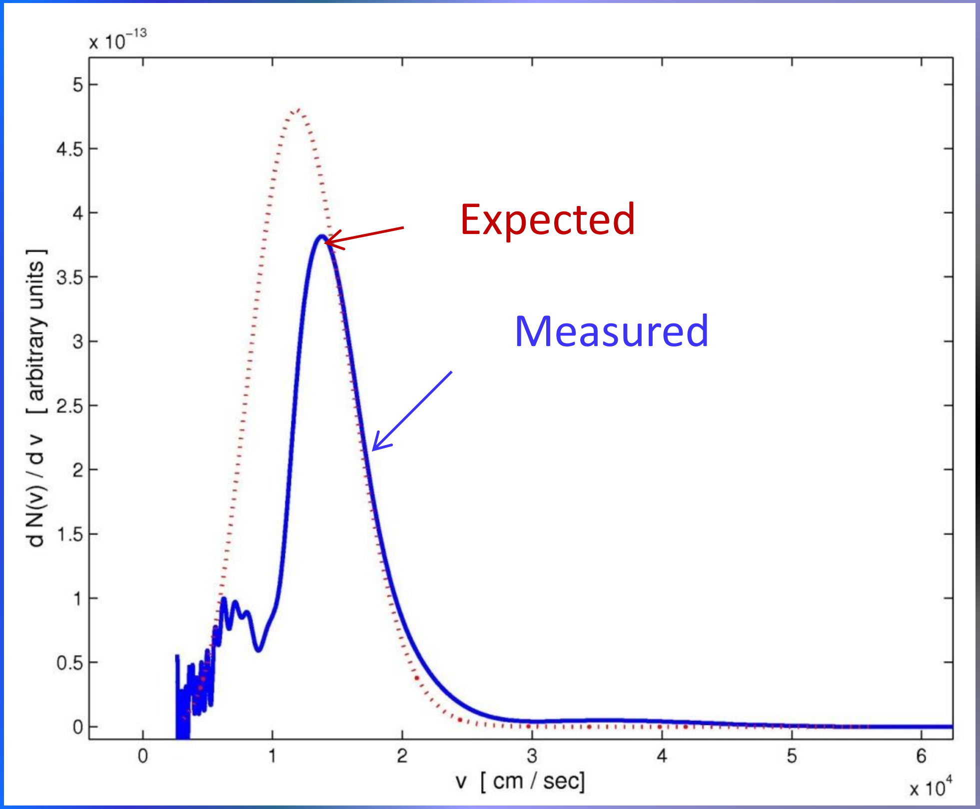
The opening angle of the “Baffled Tube” (currently 9 mrad – half angle) is supposed to match the atomic beam divergence. If the atoms hit the inside surface of the “Baffled Tube”, they lose polarization !



Velocity dependence (simulations)



Measured velocity spectrum



1. The velocity spectrum is shifted up significantly.
2. The measured beam divergence was 8 mrad.

This is a clear indication that atomic collisions define the beam intensity and spectrum. Low velocity atoms have large scattering cross section and are lost from the beam. High velocity atoms survive, and they have small divergence !

Other possible explanations: scattering near the nozzle, nozzle temperature is higher than we expect. We really need to measure divergence !!

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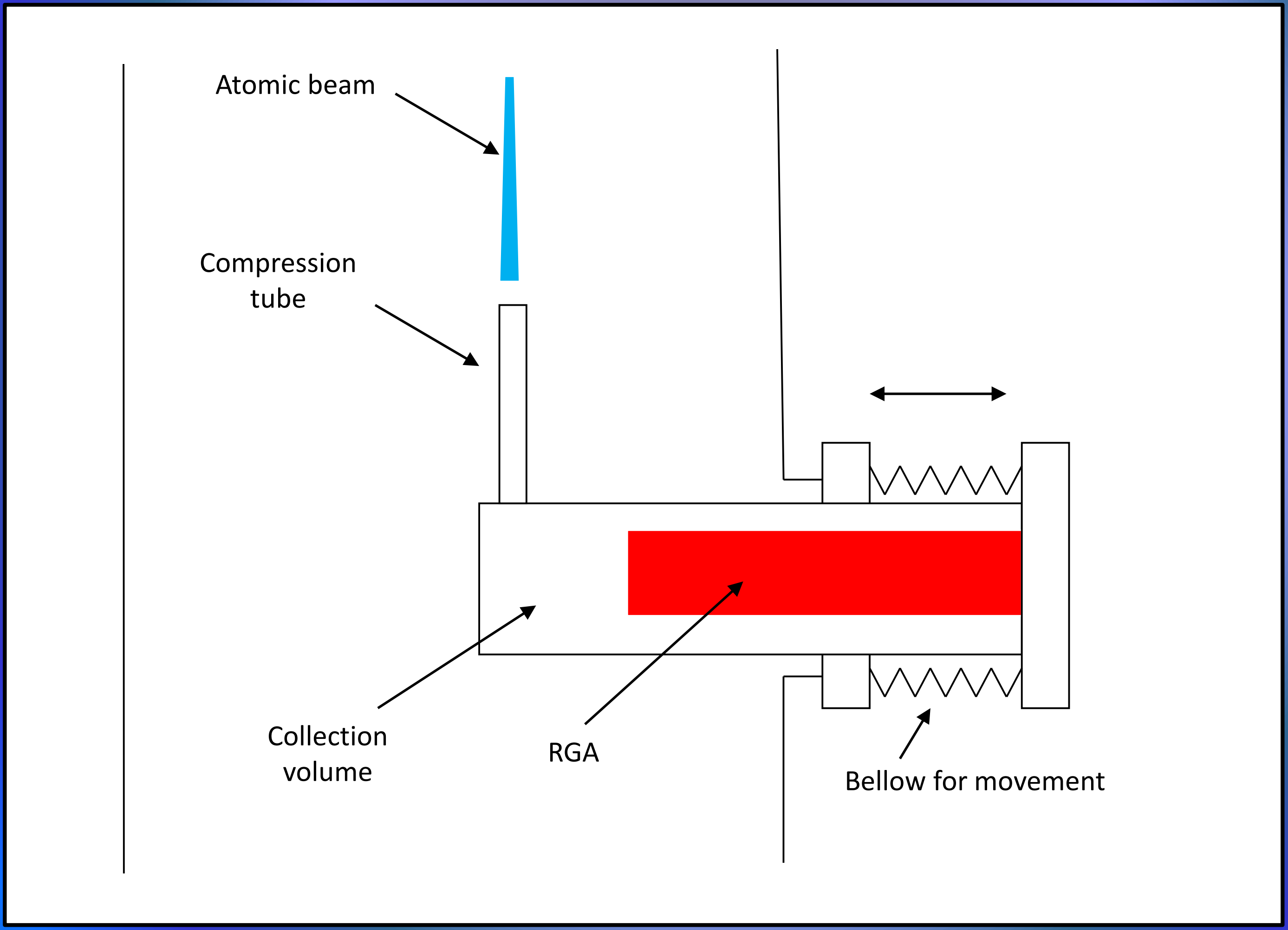
Divergence measurements

Compression tube



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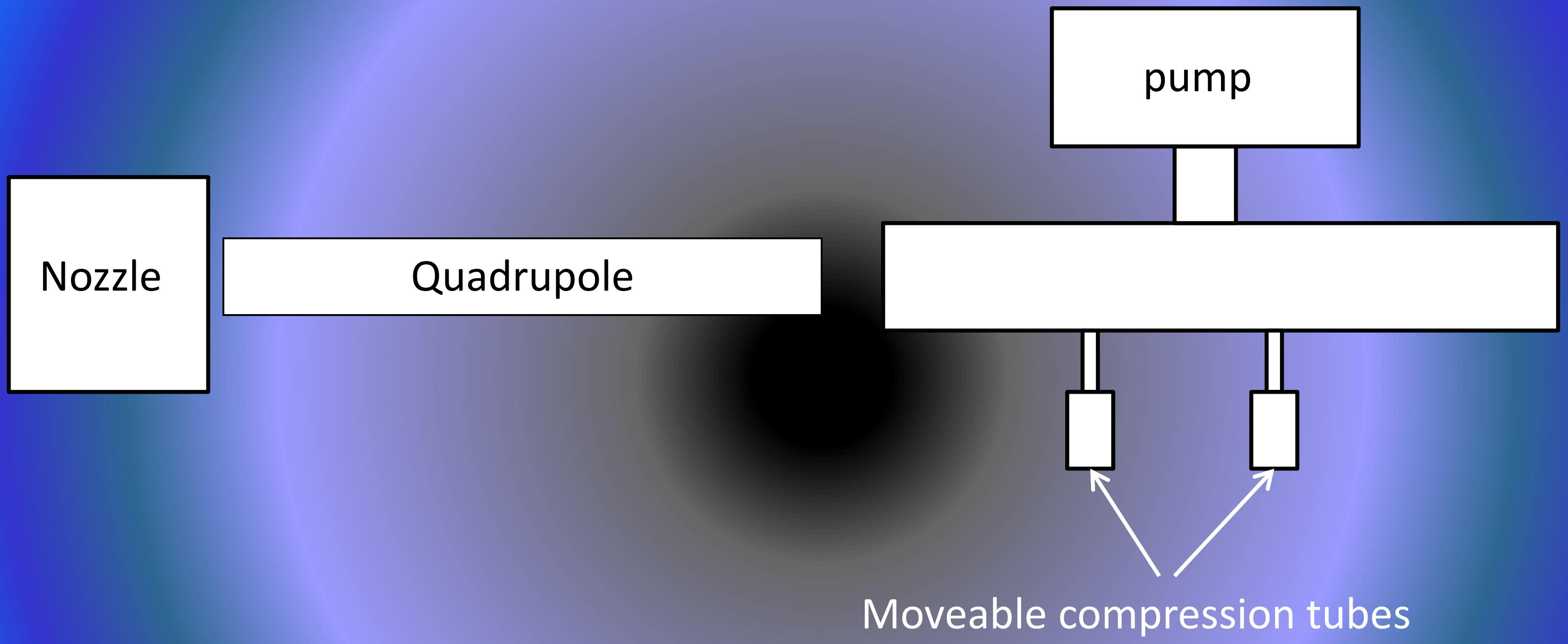
Divergence measurements



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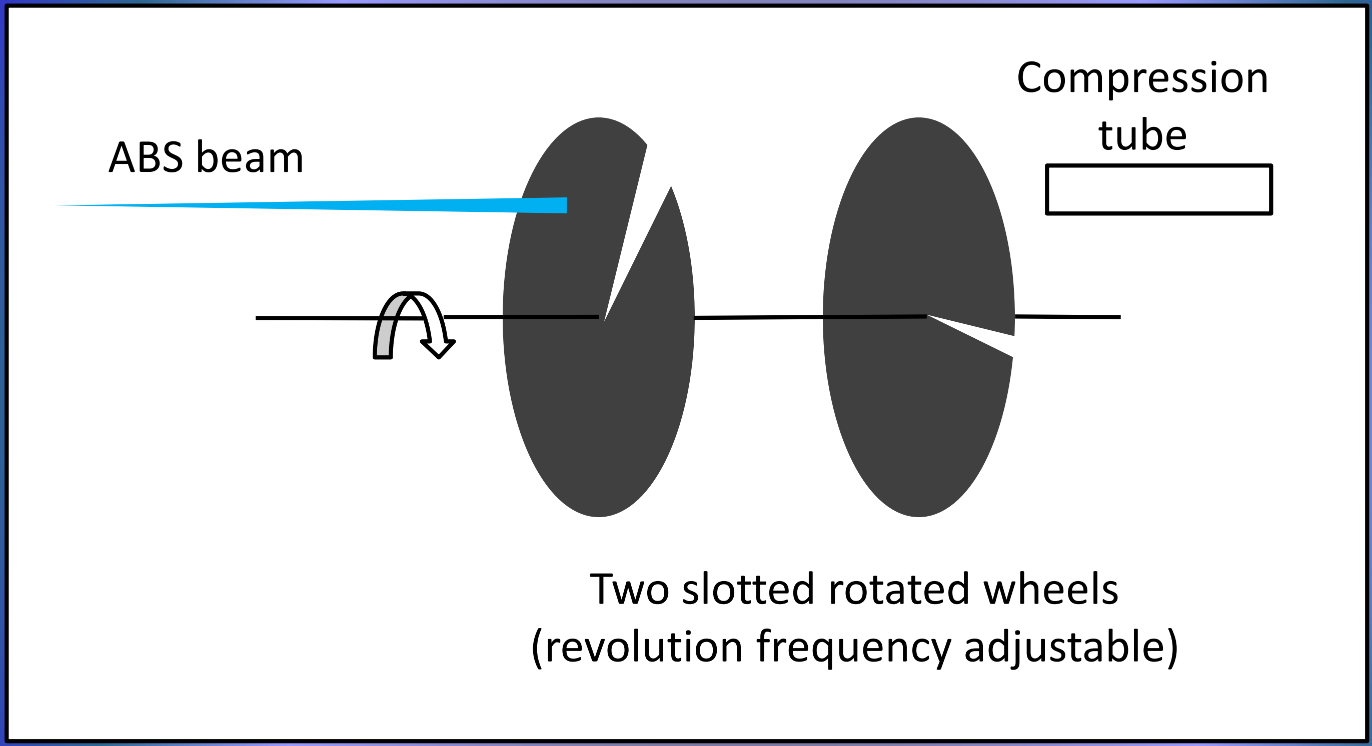
Velocity profile measurements



This is more expensive measurement – it requires rotated wheels in vacuum.

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