LOW INTENSITY
ULTRA BRIGHT ELECTRON SOURCE

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Working Group

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Brightness & Degenerate Parameter

$$dN = \frac{dx dp_x \, dy dp_y \, dz dp_z}{h^3}$$

$$dN = \frac{dx d\beta_x \, dy d\beta_y \, dz d\beta_z}{(2\pi)^3 \lambda\!\!\!^{-}{}_C^3}$$

$$N = \frac{\epsilon_x \, \epsilon_y \, \epsilon_z}{\lambda\!\!\!^{-}{}_C^3}$$

$\lambda\!\!\!^{-}{}_C = 3.86 \; 10^{-11} \; cm$

Number of particles per elementary volume

$$\delta_F = \frac{N_e}{N} = \frac{N_e}{\epsilon_x \, \epsilon_y \, \epsilon_z} \lambda\!\!\!^{-}{}_C^3 = B \lambda\!\!\!^{-}{}_C^3$$

For fermions Pauli exclusion principle limit value of δ_F

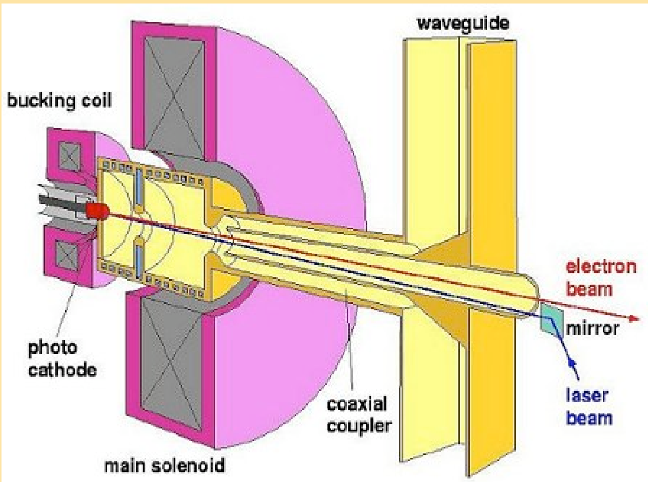
$\delta_F < 1$

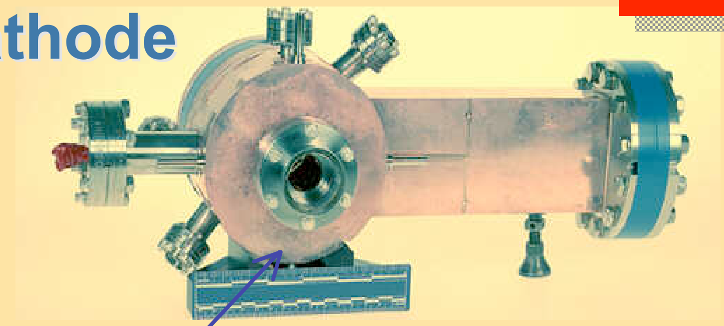
In copper $\delta_F = .995$

High intensity sources (10-100 A)

$\delta_F \sim 10^{-12}$

RF Gun with Photocathode





Charge densities up to 10^5 A/cm^2

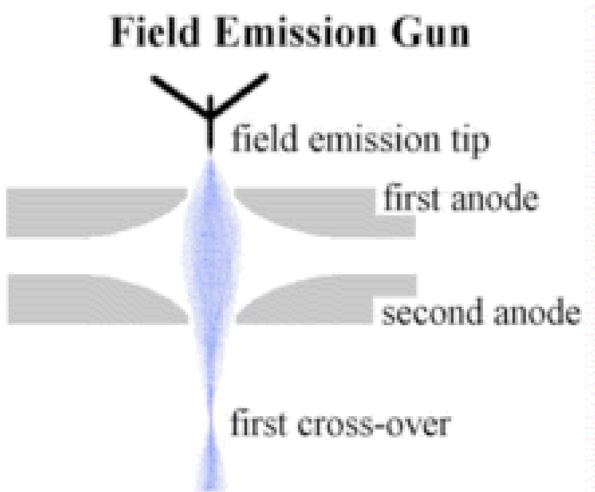
ATF (BNL) Gun III (LINAC Injector):
- Energy ~ 2 MeV
- Normalized rms emittance of 2.6 mm mrad
- Charge of 1 nC
- Pulse length of 10 ps
- RF = 2856 MHz (1 MV/cm)

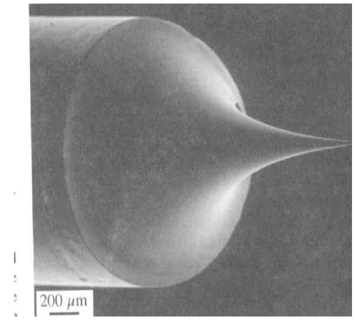
Gun for LCLS

$\delta_F \sim 4\ 10^{-12}$

Low intensity sources (1-10 nA)

Field Emission Electron Gun





THERMO Electro Corporation:
- Field at the cathode tip ~ 10 MV/cm
- 100 nm spot size at 5 nA sample current
- Current density ~ 50 A/cm^2
- Application: Electron microscope

Current densities on sample up to 10^5 A/cm^2

$$\delta_F \sim 5\ 10^{-7}$$

Electron effective temperature
$kT_e \sim .15 - .2$ eV

Modern developments including “nanotube” $\delta_F \sim 5\ 10^{-6}$

Main ideas

Cs^{133} $kT_{Cs} \sim 26$ meV

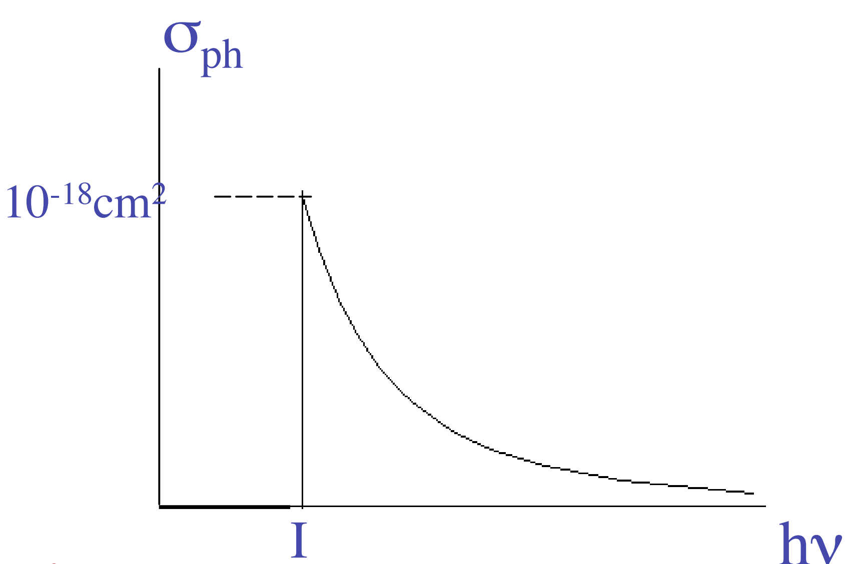
$kT_e \sim 26 \text{ meV } m_e/M_{Cs} \sim 10^{-7}$ eV

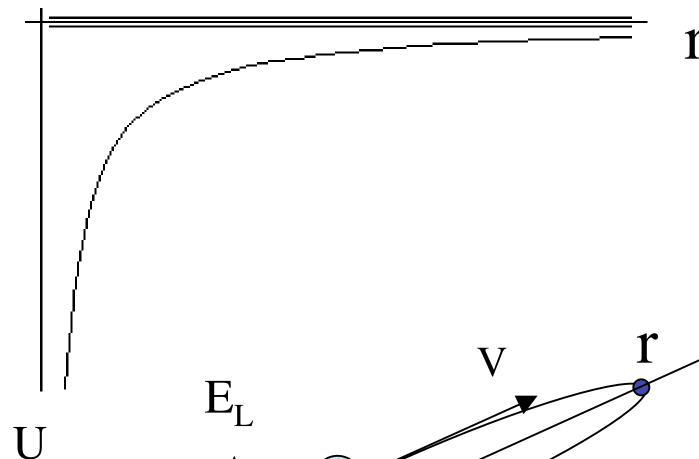
Plasma with hot ions and extremely cool electrons

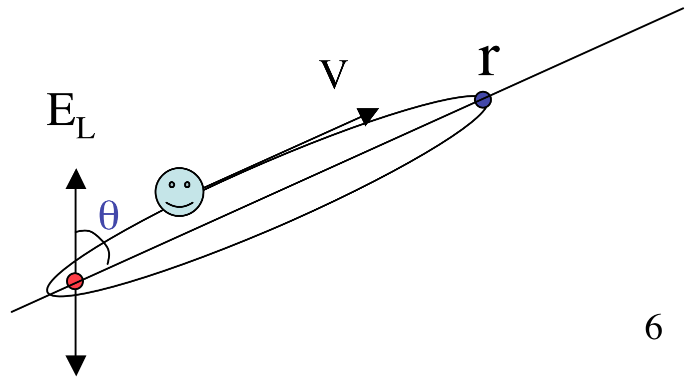
Compare with $kT_e \sim .15 - .2$ eV

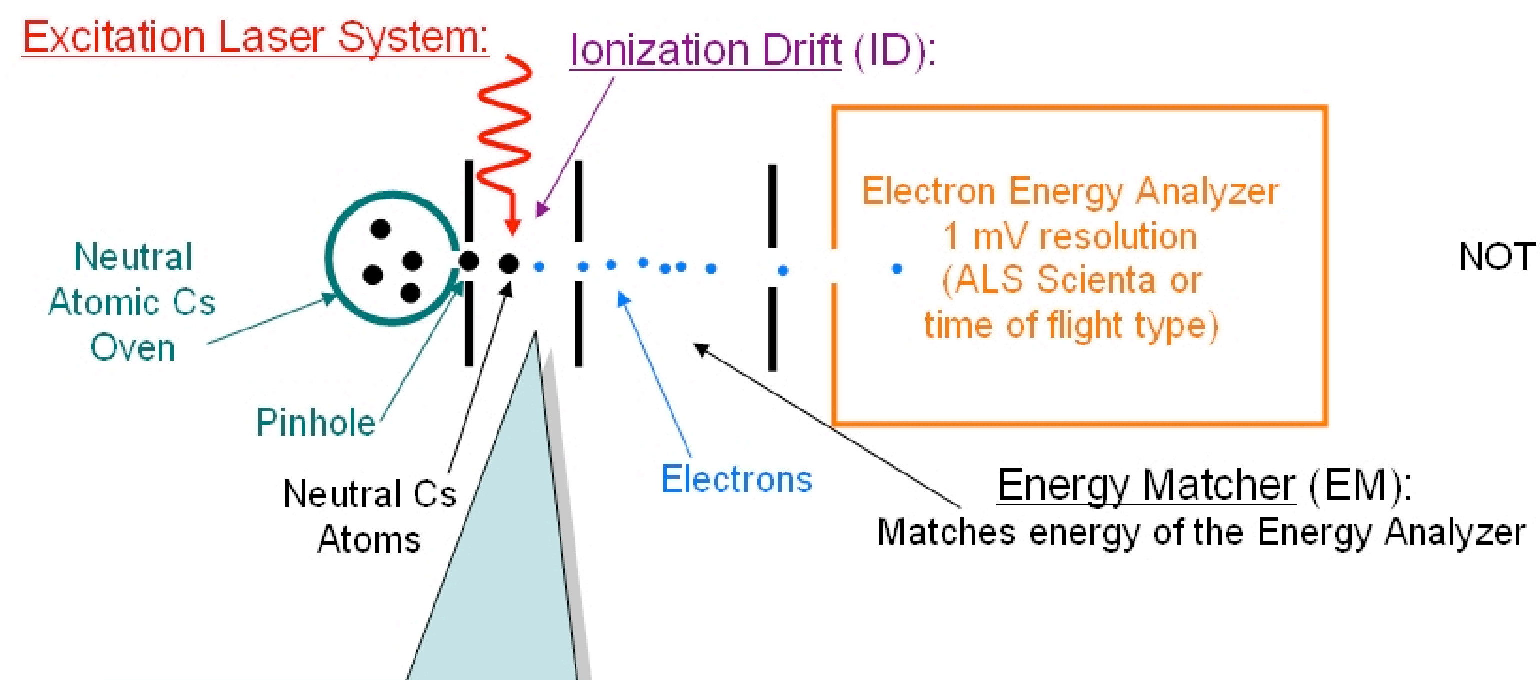
Problems: space charge when one tries to separate electrons and ions

Solution: make electrons one by one low intensity (< 1pA) high brightness

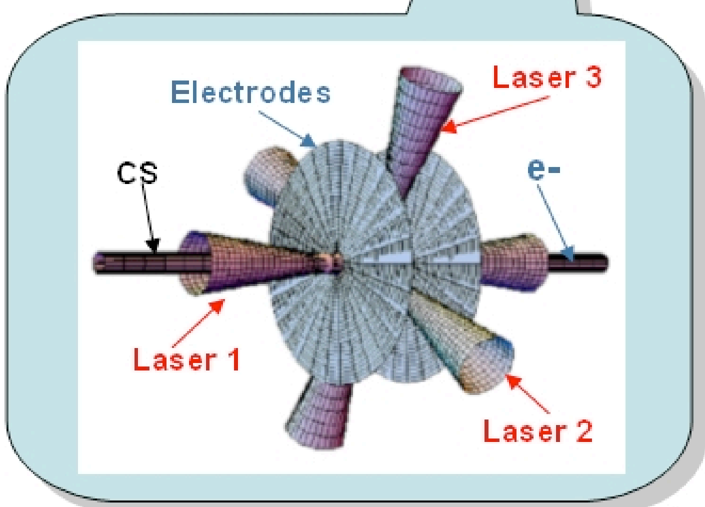


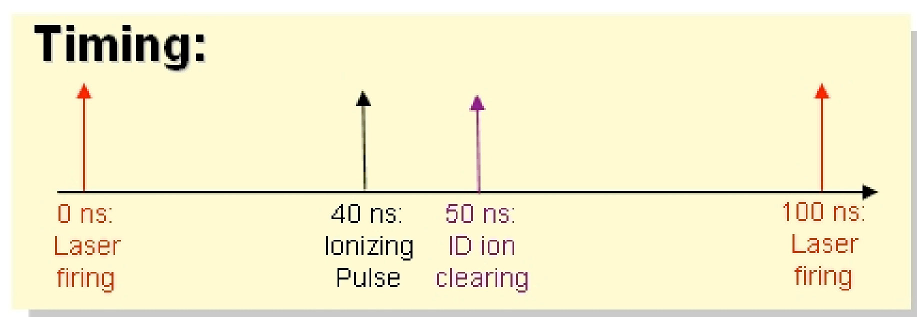





Excitation Laser System:
Ionization Drift (ID):
Neutral
Atomic Cs
Oven
Pinhole
Neutral Cs
Atoms
Electrons
Electron Energy Analyzer
1 mV resolution
(ALS Scienta or
time of flight type)
Energy Matcher (EM):
Matches energy of the Energy Analyzer

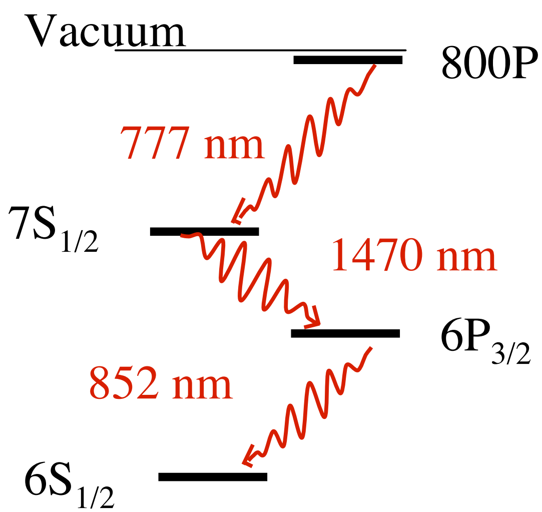
NOT TO SCALE


Electrodes
Laser 3
CS
e-
Laser 1
Laser 2


Timing:
0 ns:
Laser
firing
40 ns:
Ionizing
Pulse
50 ns:
ID ion
clearing
100 ns:
Laser
firing

Electron Excitation

In the interaction region,defined by the overlap of the Lasers and atomic beam, we excite on average one Cs atom per laser pulse to a Rydberg state very close to vacuum (~-10^{-5} eV).The electron in the excited atom will have a large kinetic energy and will start to move from the ion.



n~1000 was populated in potassium [1]

M.T.Frey,X.Ling,B.G.Lindsay,K.A.Smith and F.B.Dunning

Waiting Period

After the laser pulse, we wait the time necessary (~40 ns) for the electron to go far from the nucleus (~65 μm) and reach the turning point of its classical orbit where its kinetic energy is negligible. At this point, a short pulsed voltage ionizes the atom, extracts the electron from the interaction region.

Electron Acceleration

DC voltage applied between next electrodes accelerates electron to desired energy.

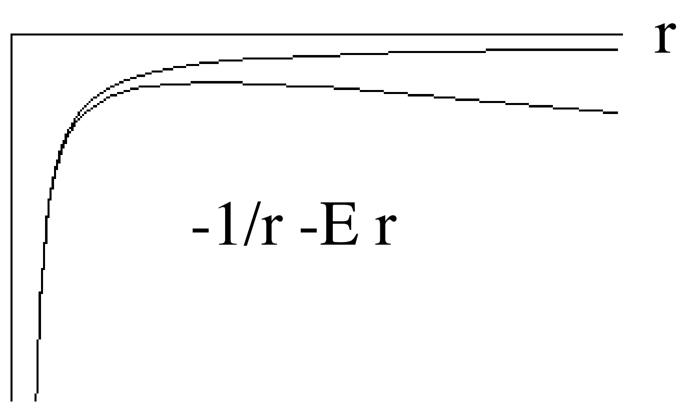
Ion Clearing

After the electron leaves the second region, a “clearing” pulsed field removes the residual ion before the beginning of the following cycle. In this way the electron produced in the next cycle does not interact with ions from previous pulses.

Residual Magnetic and Electric Fields

Magnetic field ~ 10^{-3} Gauss will degrade brightness. The source needs to be contained within suitable magnetic shielding. (2 layers of μmetal shield)

For n~ 800 stray electric fields need to be constrained within10^{-4} V/cm. (Schottky-barrier lowering)



Expectations

Semiclassical treatment:

$$\epsilon_{x,y} = \frac{1}{2}\sqrt{(n\,\Omega\tau)^2 + \left(\frac{3\pi}{2\,\Omega\tau}\right)^2}\,\langle Sin^2\theta\rangle\,\langle Sin^2\varphi\rangle$$

For Cs; $w \sim 1+3\,\mathrm{Cos}^2\theta$;

$\langle \mathrm{Sin}^2\theta\rangle\langle \mathrm{Sin}^2\varphi\rangle = 4/15$

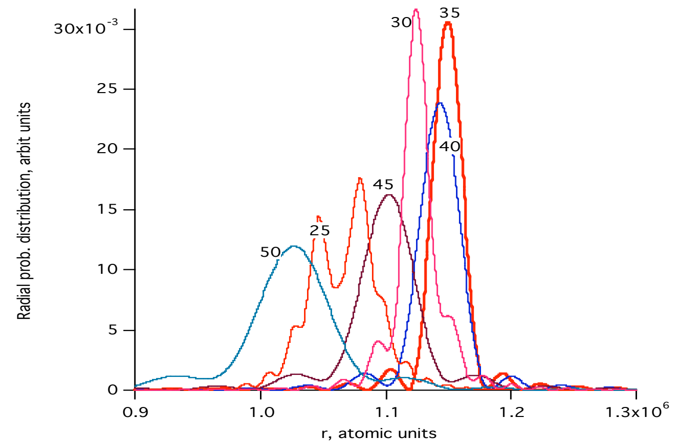
For n=800, optimum $\tau = 1$ ns

and

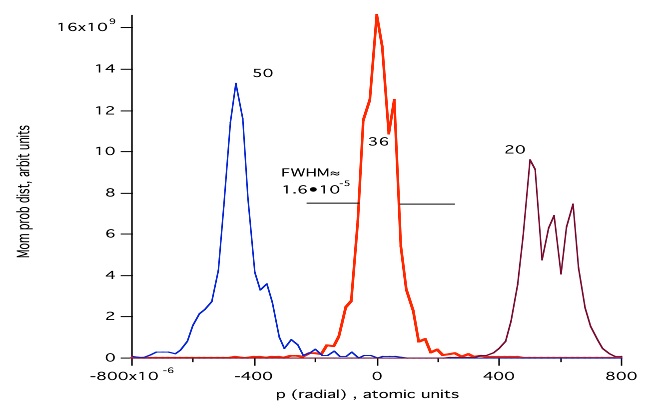
$\varepsilon_{x,y} = 2/15\,\sqrt{3\pi n} \sim 11.5$

$\delta_F \sim 10^{-3}$

Quantum treatment (E.D. Commins)



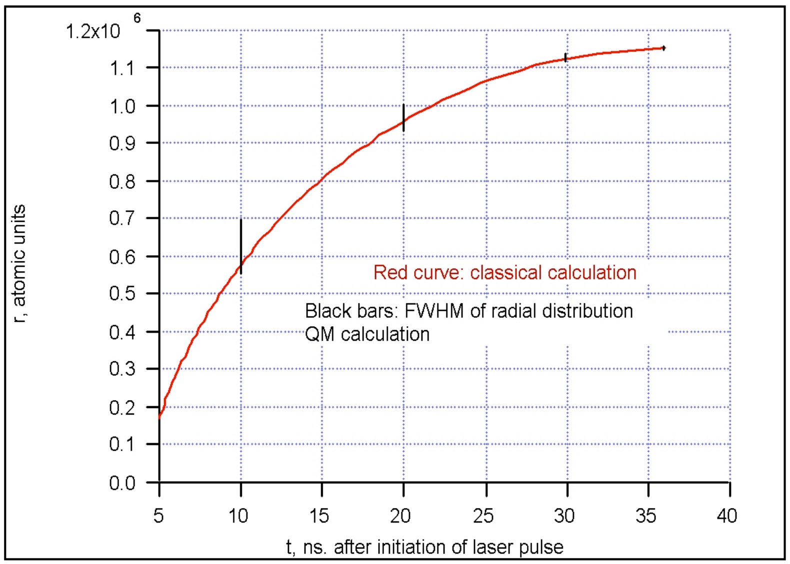
Radial wave-packets for t=25,30,35,40,45,and 50 ns after initiation of Gaussian laser pulse, centered on 7s-759p transition.

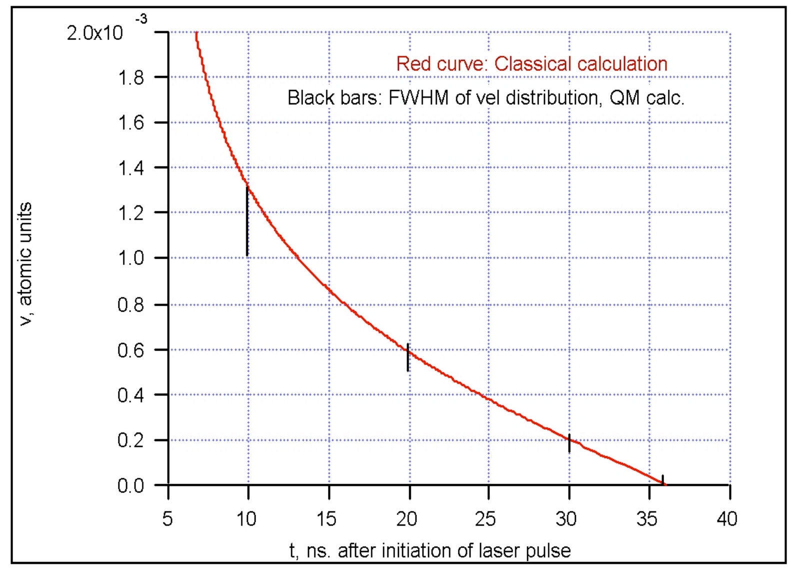


Radial momentum distributions for t=20, 36, and 50 ns after initiation of the laser pulse.

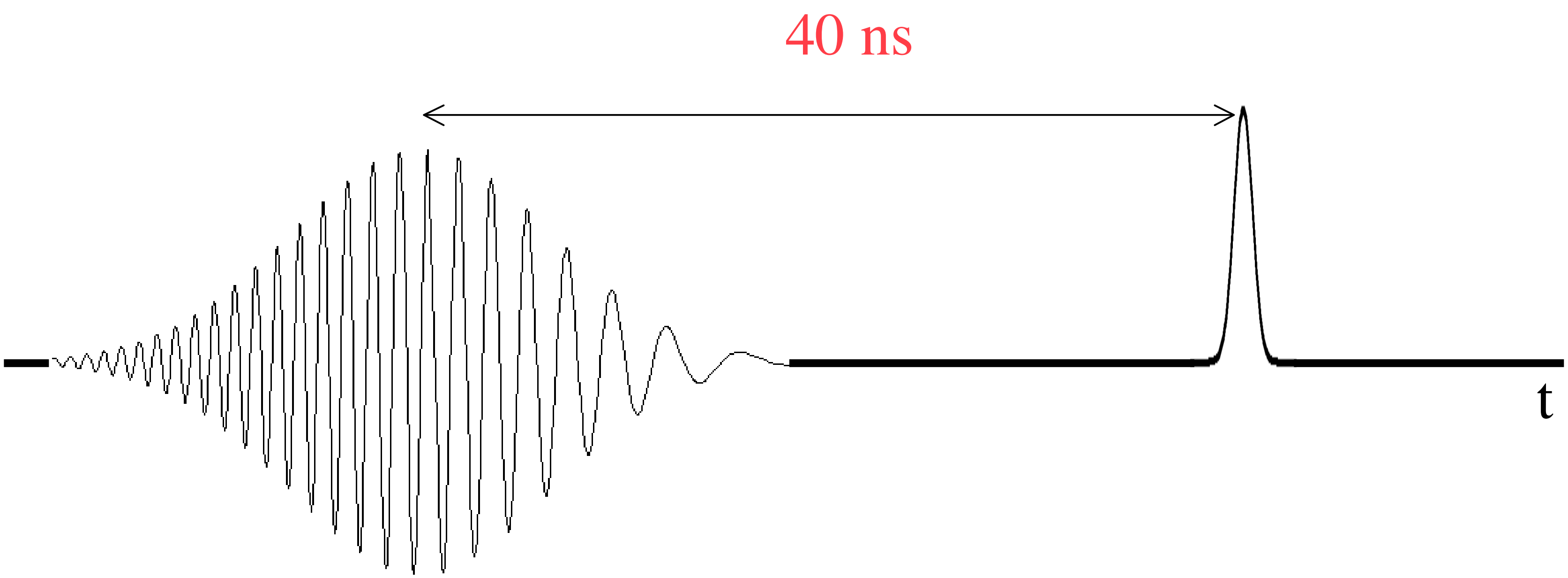
$\varepsilon_{x,y} \sim 12$

Quantum calculation (E.D. Commins)



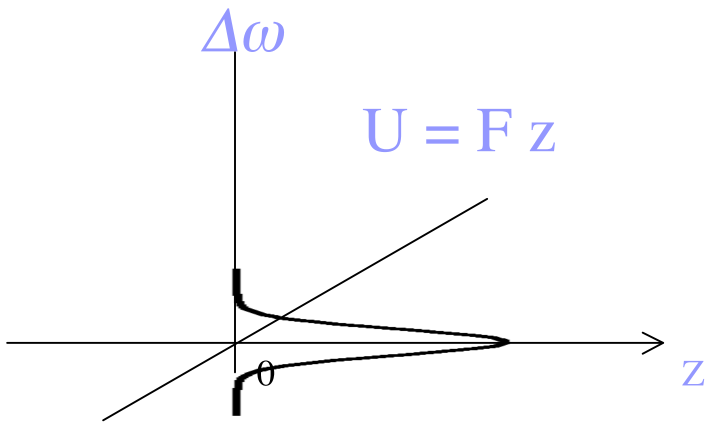


Chirp pulse excitation

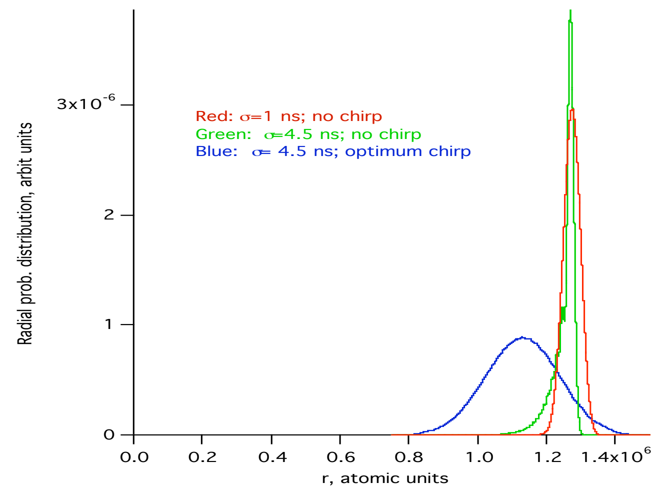


$$\epsilon_{x,y} = \frac{1}{2}\sqrt{(n\,\Omega\tau)^2 + \left(\frac{3\pi}{\Omega\tau}\right)^2}\ \langle Sin^2\theta\rangle\ \langle Sin^2\varphi\rangle$$

Quantum Picture of Chirp Pulse Excitation



$$\int e^{-\frac{(\Delta\omega\,\tau)^2}{1+4\eta^2} - i\,\frac{2\,\eta\,(\Delta\omega\,\tau)^2}{1+4\eta^2} - i\,\frac{3\,\pi}{4}\,\frac{(\Delta\omega)^2}{\alpha\,F} + i\,\frac{\Delta\omega\,D}{F}}\, d\Delta\omega$$



$$\epsilon_{x,y} = \frac{3\,\pi}{4\,\Omega\tau} < \mathrm{Sin}^2\,\theta > < \mathrm{Sin}^2\,\varphi >$$

E.D.Commins numerical calculations

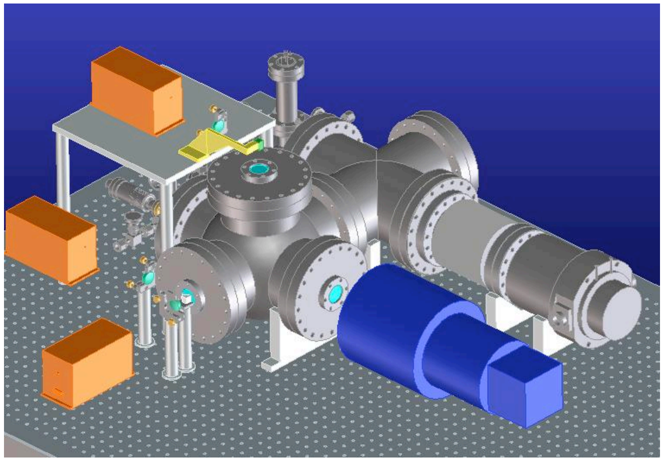
$\varepsilon_{x,y} \sim 1$

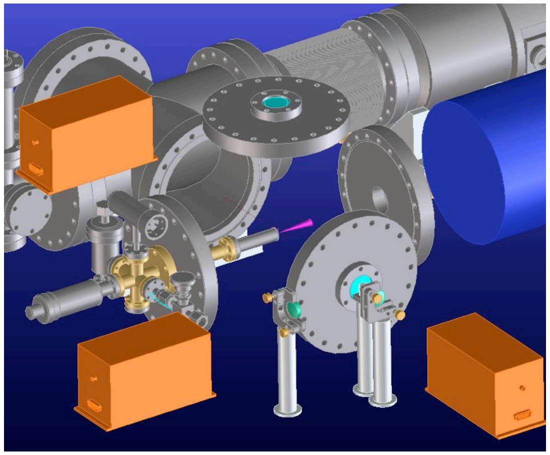
$\varepsilon_{x,y} = 2$; including initial source size and atomic velocity spread

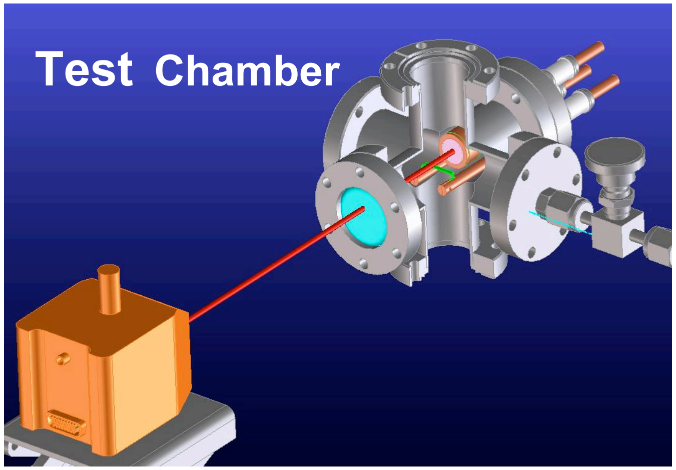
$\delta_F \sim .1$

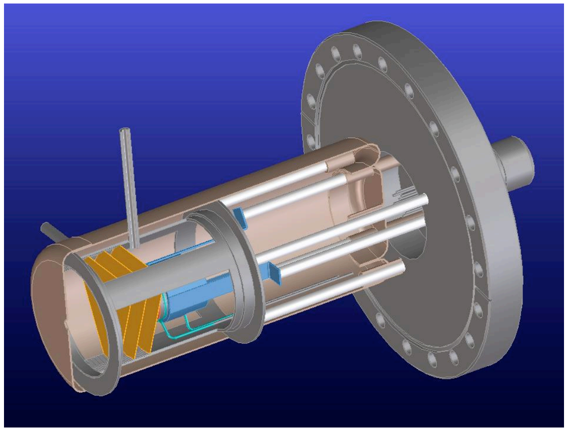
We are really doing it

Two years LDRD project
$130 k and $130 k









Main problems

Known:

- •Stray fields
  Electric patch fields < 10^{-4} V/cm
  Magnetic fields < 10^{-3} Gauss
- •Photo-ionization by laser light scattered on electrode surfaces: >777 nm; cesium coating of surfaces
- •Mirror charge problems (very low energy and energy spread of electrons)
- •Electronics problems: Short intense electric field pulses: (ringing problems)
- •Aberrations

Unknown?

In principle, each problem can be solved,
but perhaps not in my lifetime.