ORSAY PHYSICS

Laser cooled cesium atoms as a focused ion beam source

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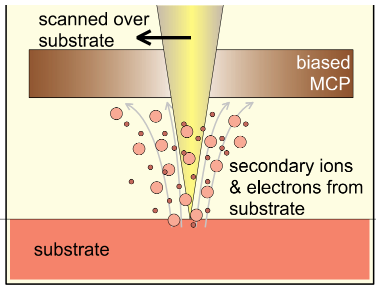
ORSAY GROUP

Outline

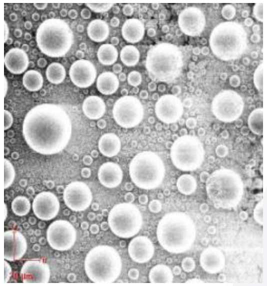
- Introduction to Focused Ion Beam (FIB)
- Why cold atoms ?
- Some cold atoms sources
- Our cesium source
- Coulomb effects
- Conclusion

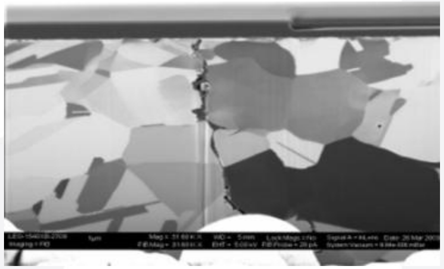
Focused Ions Beam (FIB) applications

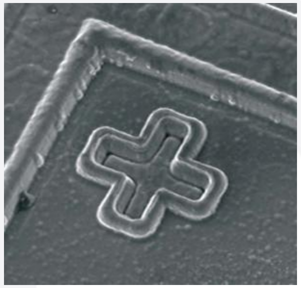
Ion/Solide Interactions

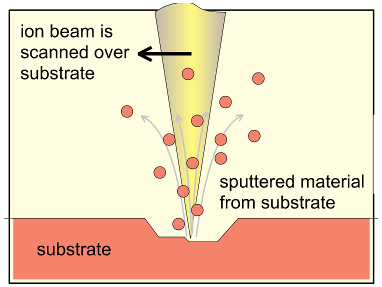


Image

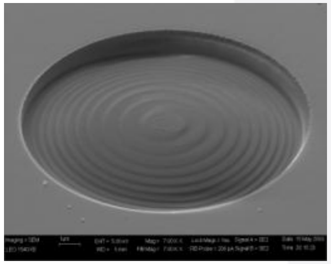


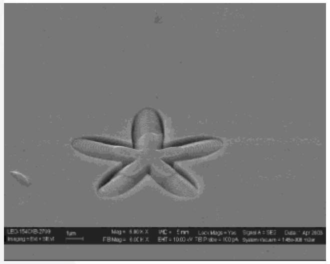


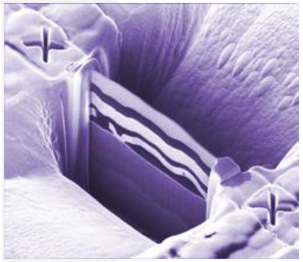


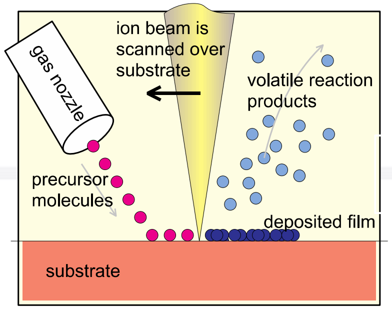


Pulverisation

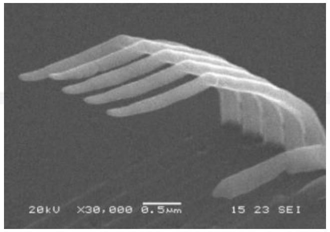


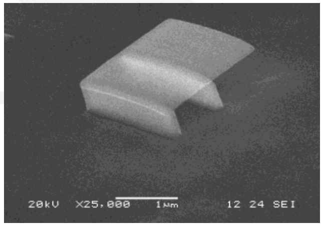


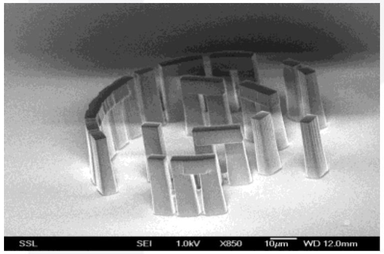




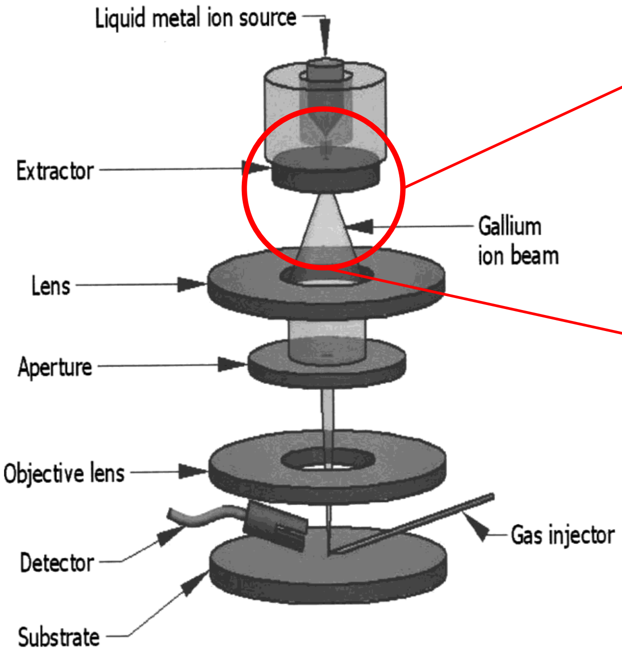
Deposition

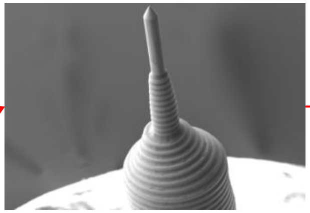






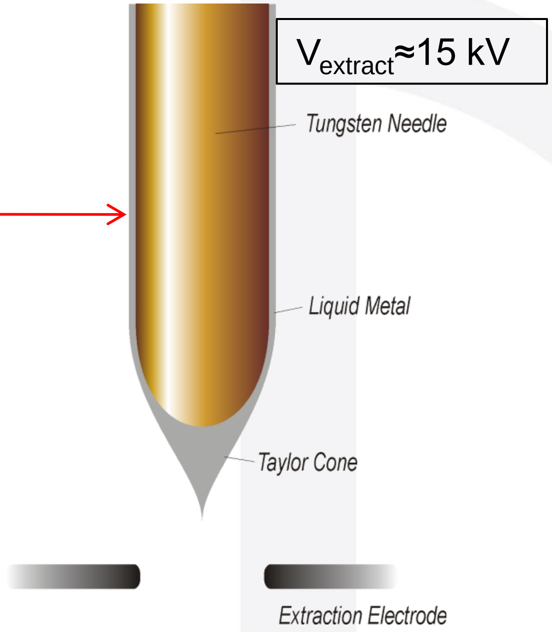
Liquid Metal Ion Source (LMIS)





Orsay Physics Ga LMIS

J.Gierak – LPN (F)



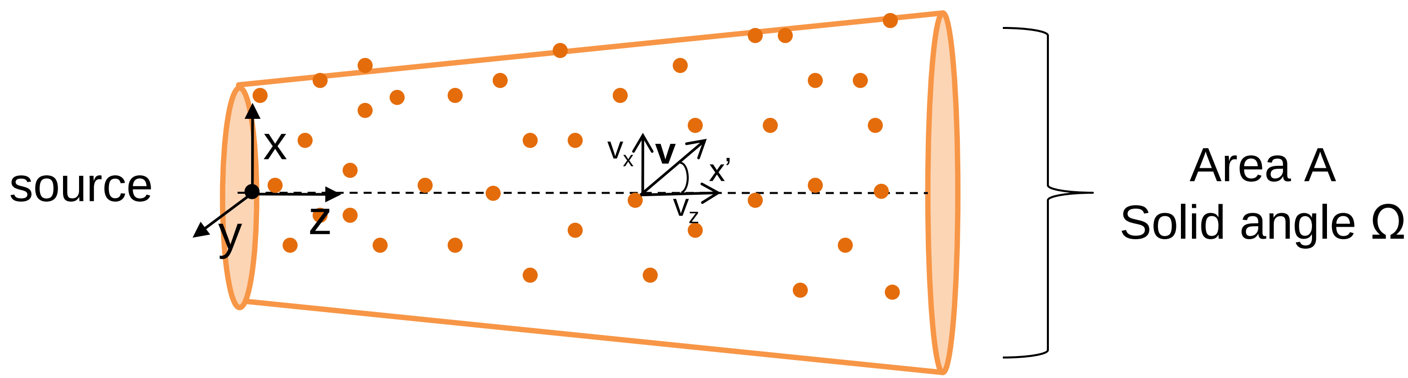
Advantages

- Really small source (virtual source ~50nm)
- High Brigthness $B \approx 10^6$ A m^{-2} sr^{-1} eV^{-1}
- Long life time> 2500 µA.h

Disadvantages

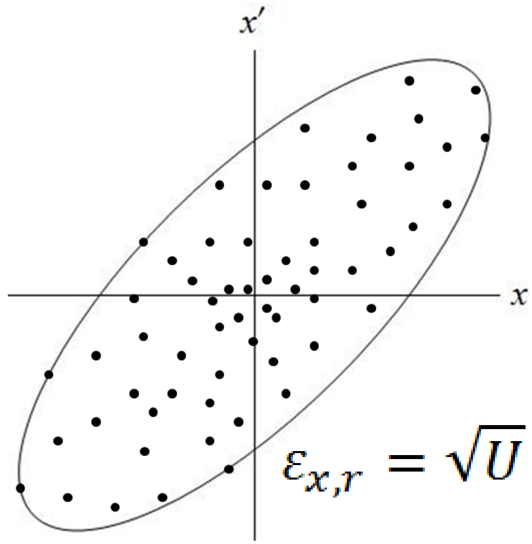
- Energy dispersion(~5 eV)
  → Chromatic aberrations
- Few atoms possible (**Ga**, Al, Au, In, Bi)
- Gallium contamination

Key parameters for a source



- Emittance

$$\varepsilon_x = \int dx\, dp_x$$



$$\varepsilon_{x,r} = \sqrt{U} \int dx\, dx'$$

- Brightness

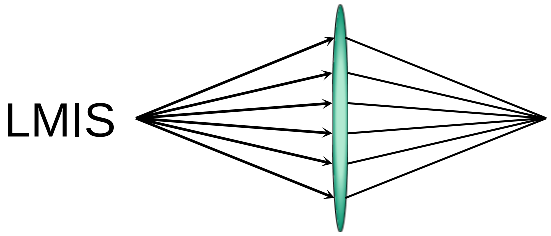
$$B_r = \frac{1}{U}\frac{I}{A\,\Omega} = \frac{I}{\varepsilon_{x,r}\;\varepsilon_{y,r}}$$

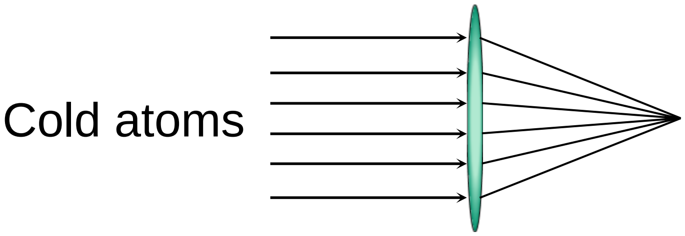
Emittance and Brightness are invariant during beam propagation (Liouville's theorem)

New idea

The idea is to obtain a large ion source without divergence to increase the brightness

➡ Cold atoms





Advantages

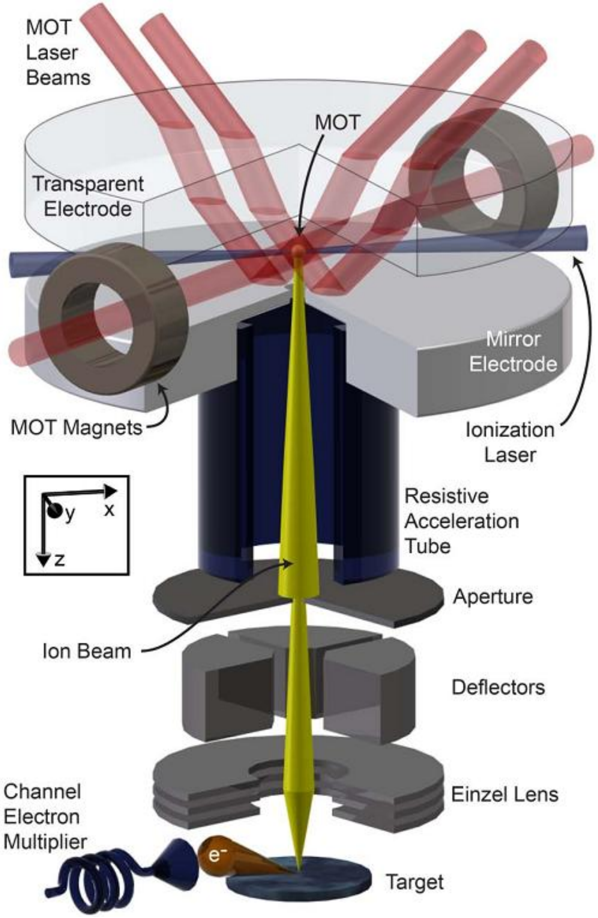
Monokinetic beam

Reduce chromatic aberrations

Ion beam with cold atoms

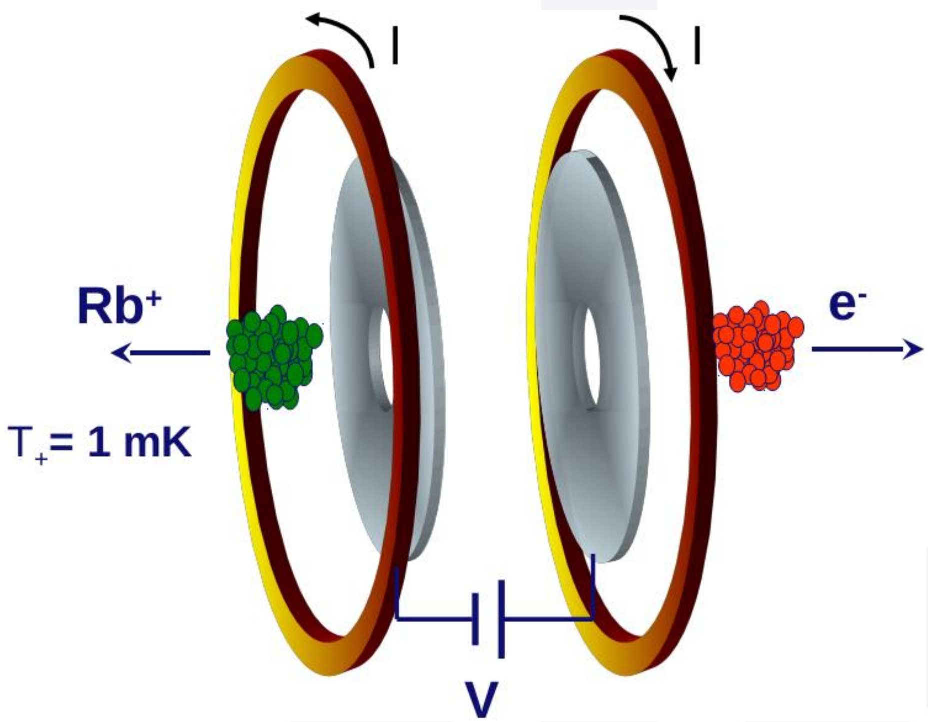
MOTIS (2008)

J. McClelland group
NIST Gaithersburg



UCIS(2009)

E .Vredenbregt and J. Luiten group
TUe Eindhoven



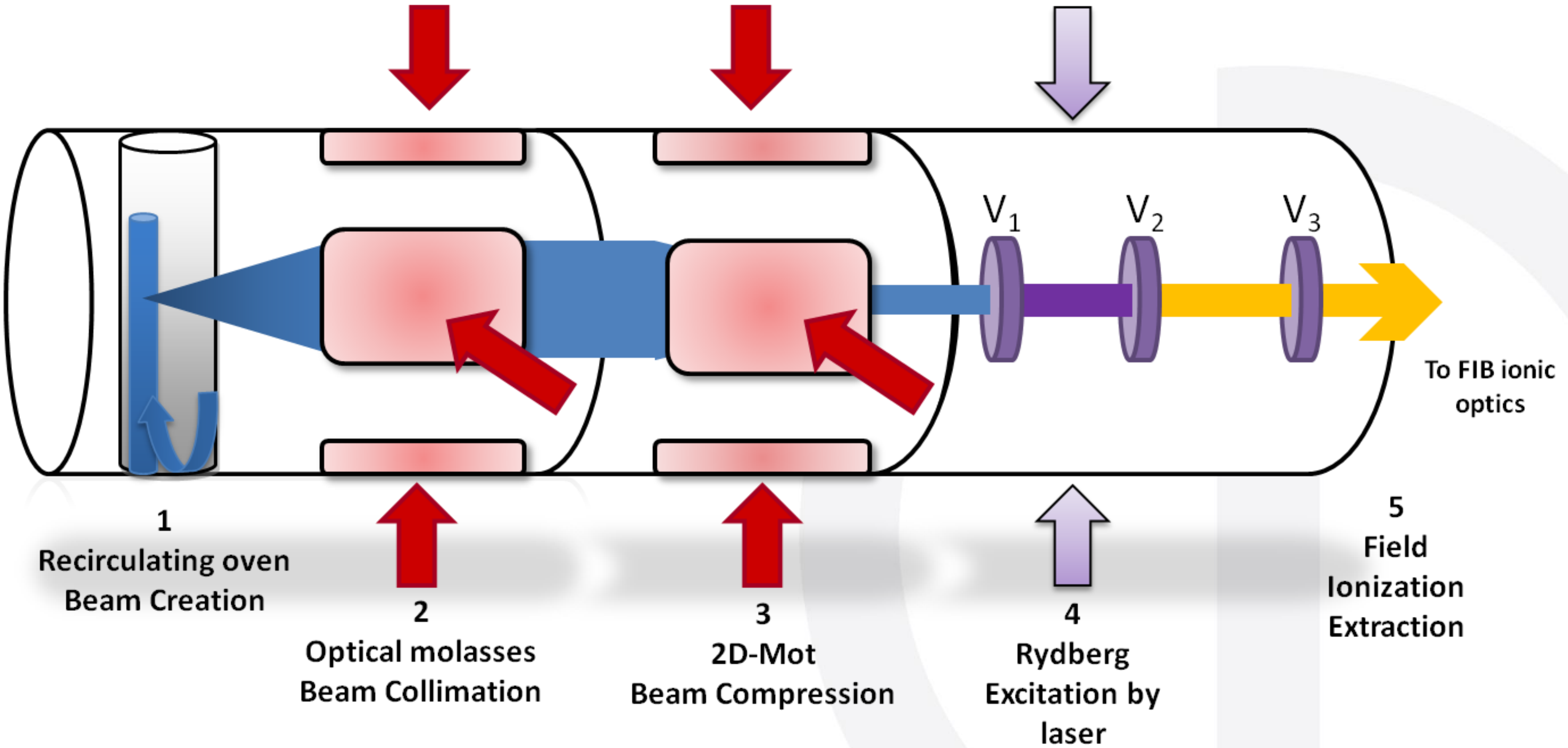
<u>Other groups :</u> F. Fuso (Pisa), D. Comparat (Orsay), R. Scholten (Melbourne) , C Adams (Durham)…

Our source

- **Goals**:
  - Continues and high courant source (~10 nA)
  - High brightness (> LMIS =10^6 $A.m^{-2}.sr^{-1}.V^{-1}$)
  - Low energy dispersion (<0.5 eV – LMIS = 5 eV)

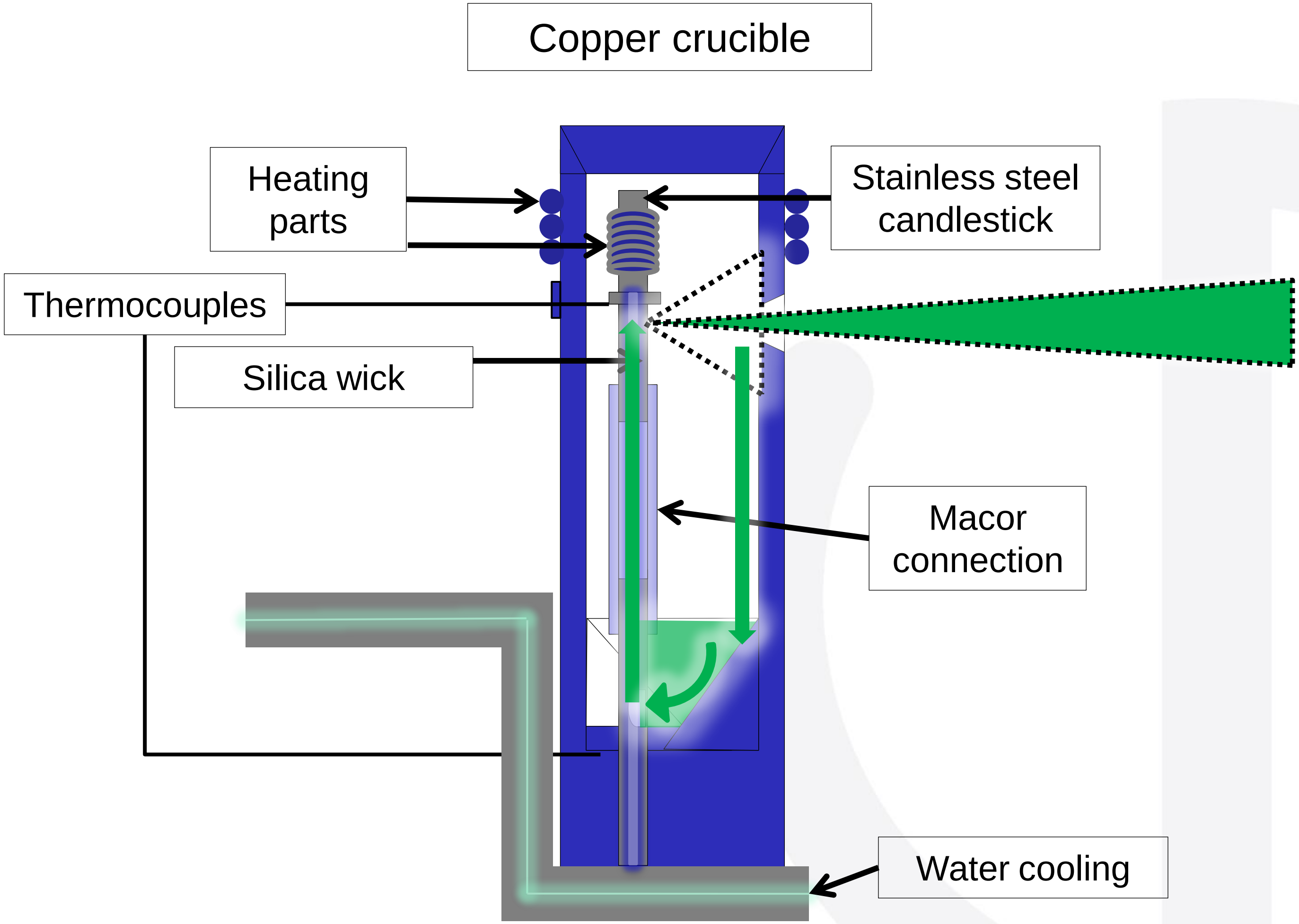
- **Our setup**:
  - Atomic cesium beam with high flux
  - Laser cooling of the atoms
  - Rydberg ionisation in electric field

Our source

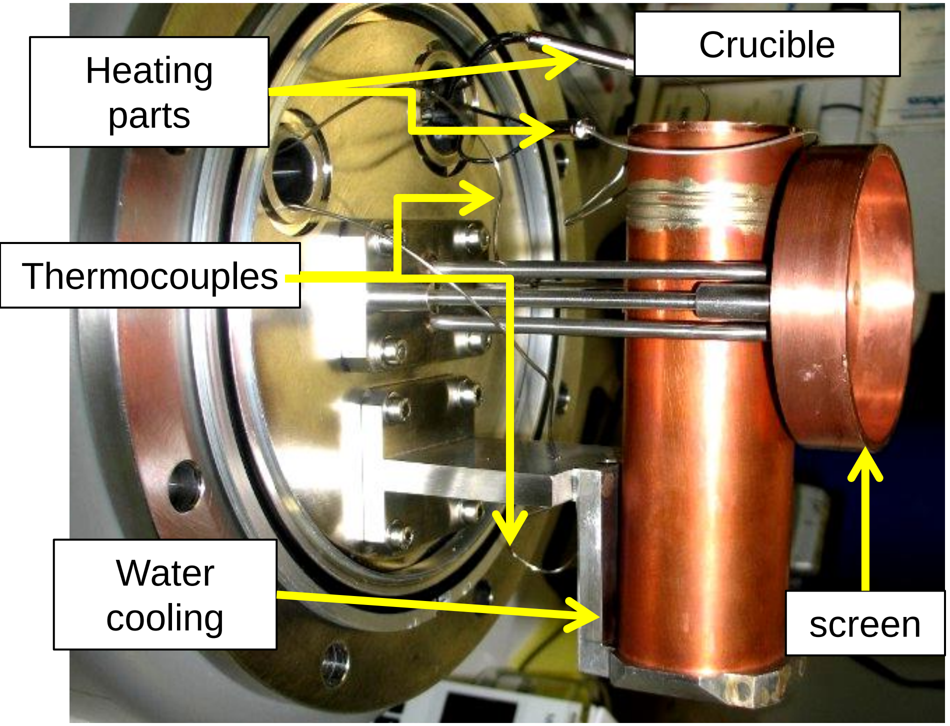


	1	2	3	4-5	
Divergence (mrad)	40	0.5	0.5	0.5	
Flux (at/s)	2.10^{14}	5.10^{13}	5.10^{13}	2.10^{10}	~3.5 nA
Diameter(mm)	2	10	1.5	0.1	

Recirculating oven

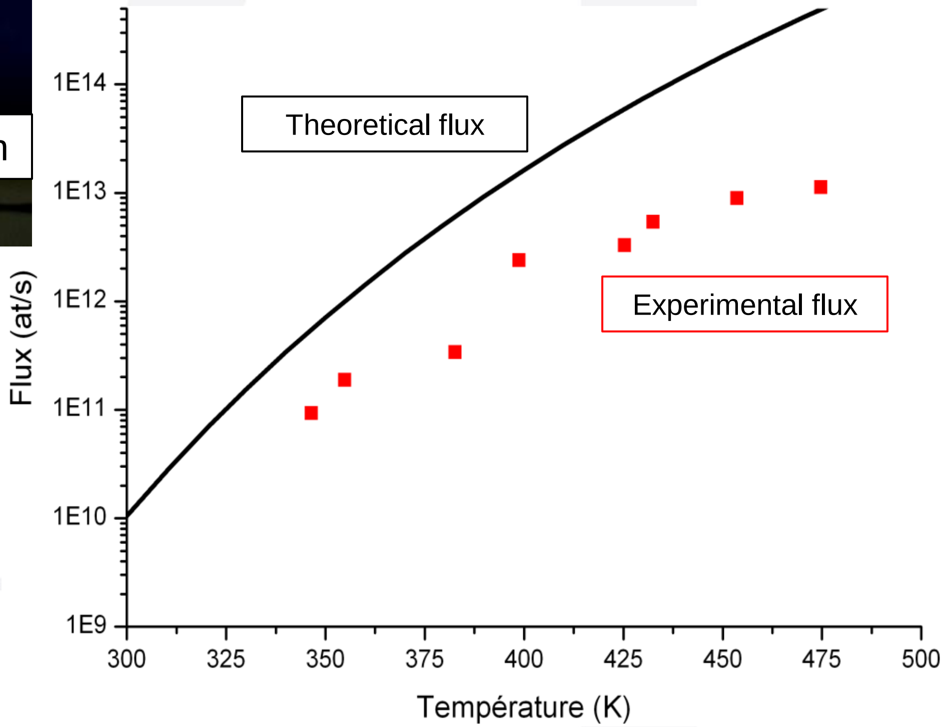


Recirculating oven

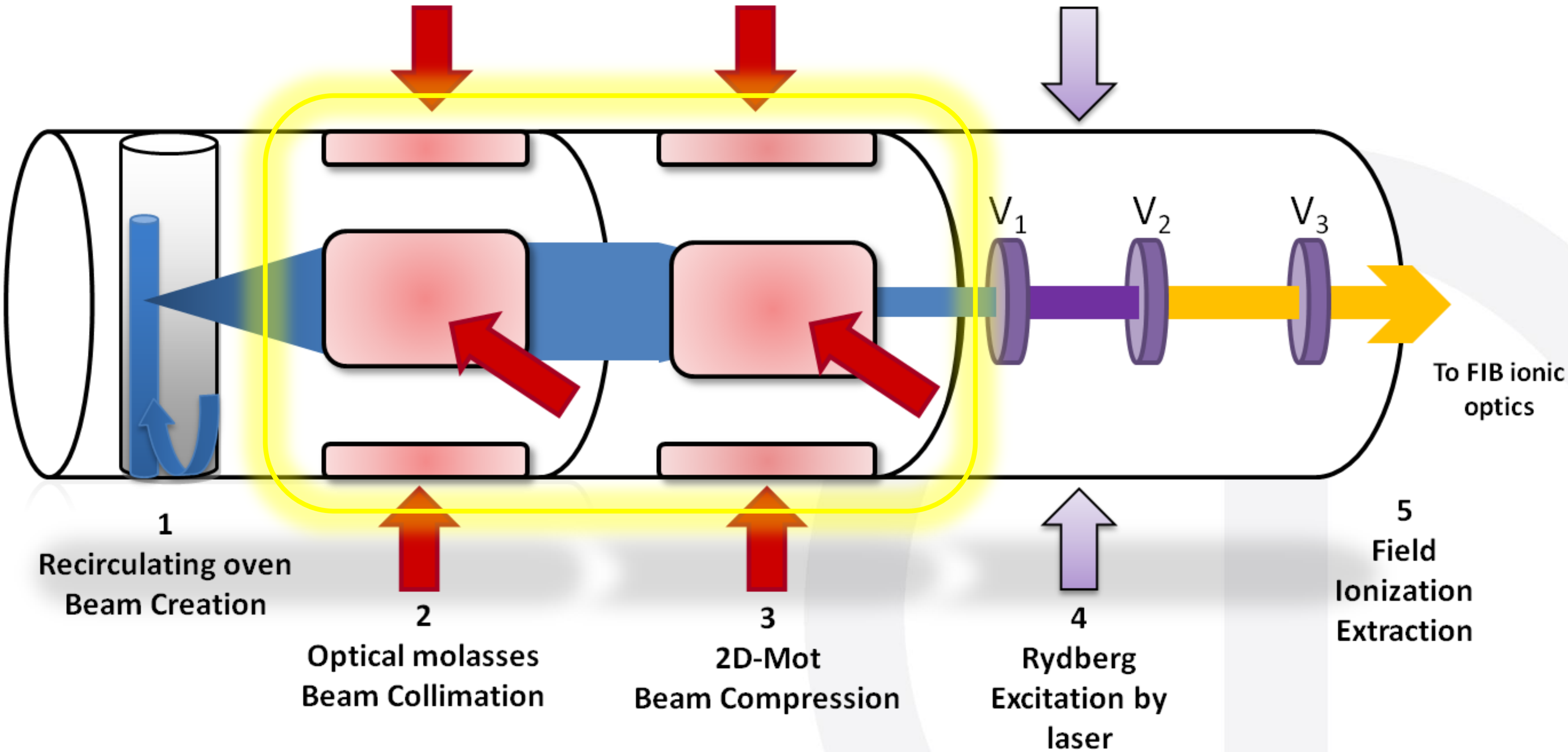


- Up to 450K thermal beam
- Silica wick limits the flux

- Theoretical flux at 450 K : 2.10^{14} at/s
- Measured : ~10^{13} at/s

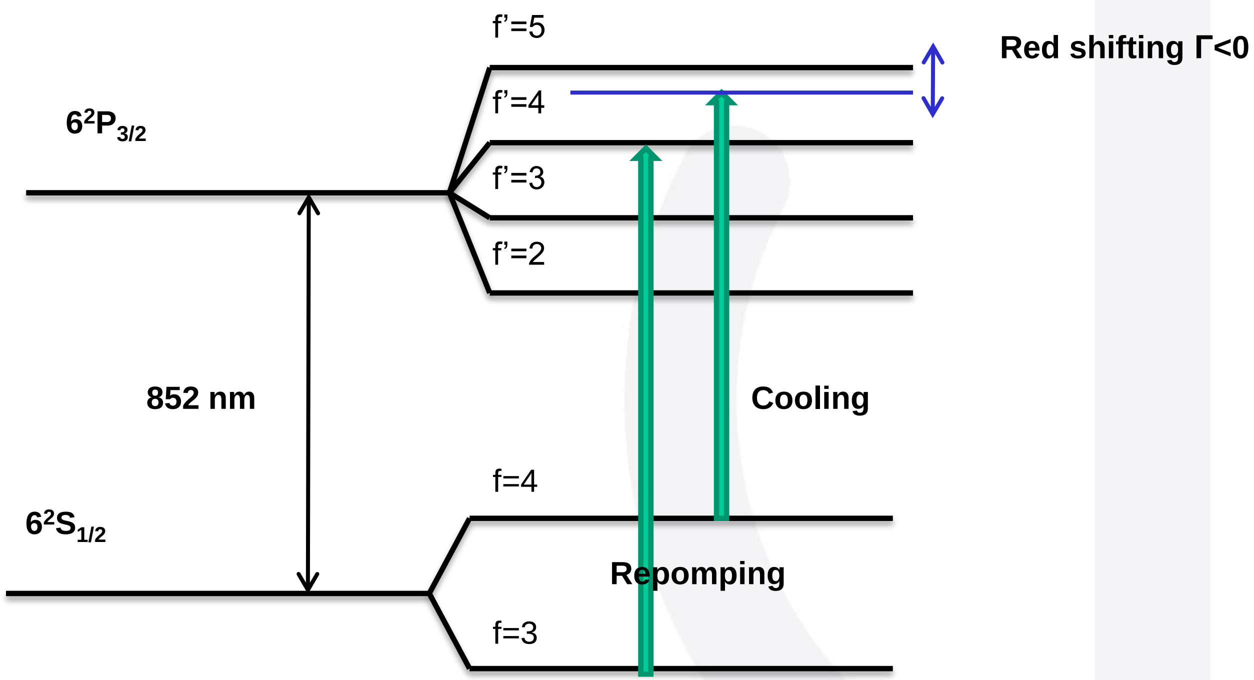


Our source



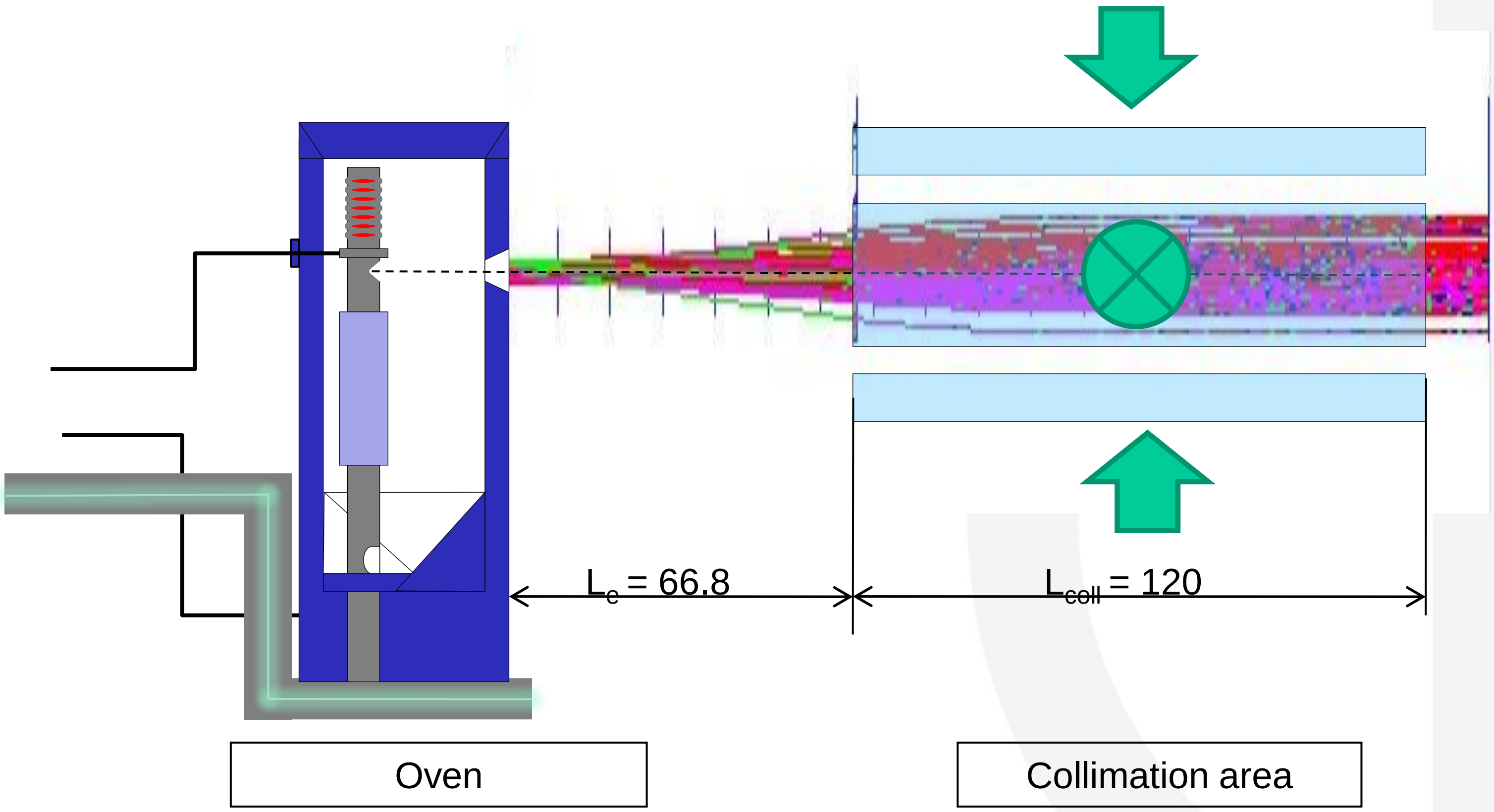
	1	2	3	4-5
Average longitudinale speed(m/s)	300	300	300	300
Divergence (mrad)	40	0.5	0.5	0.5
Flux (at/s)	10^{13}	5.10^{13}	5.10^{13}	2.10^{10}
Diameter(mm)	2	10	1.5	0.1

Collimation



Cesium energy levels

Collimation

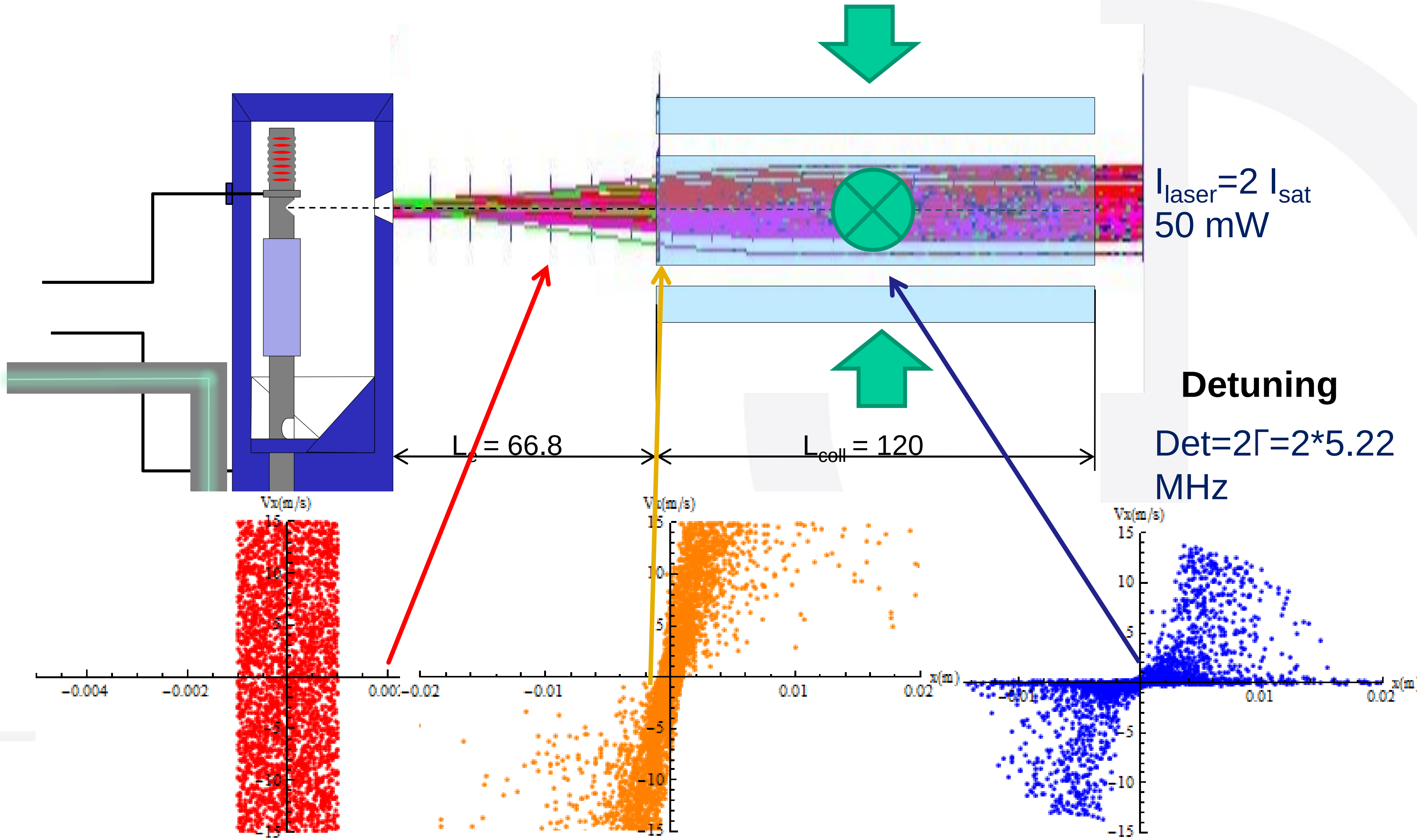


I_{laser}=2 I_{sat}
50 mW

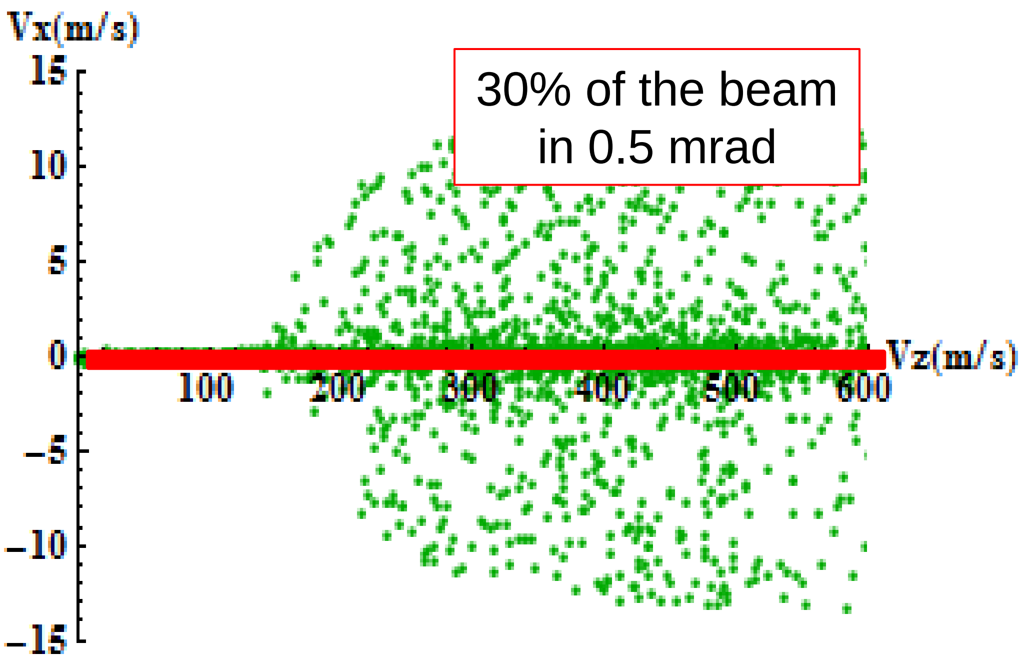
Detuning

Det=2Γ=2*5.22 MHz

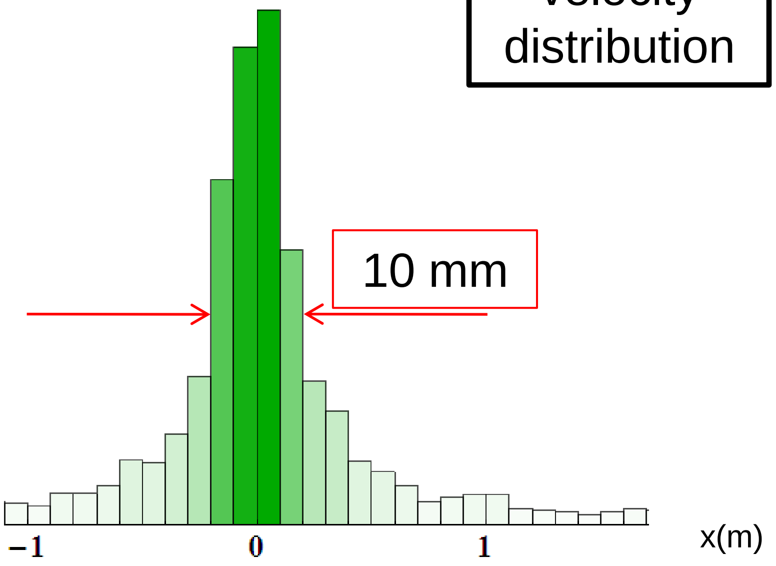
Collimation



Collimation



Transverse velocity distribution

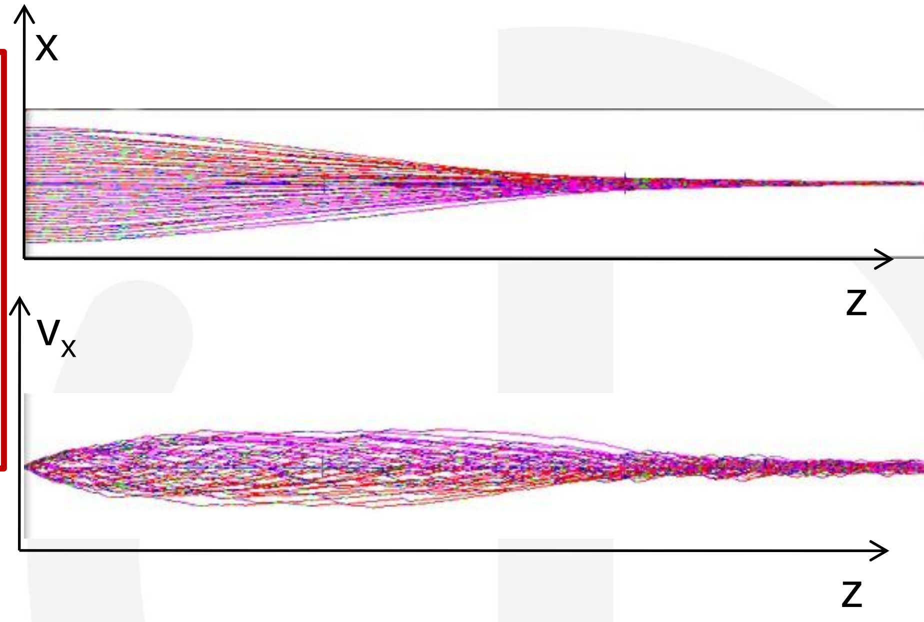


After collimation:

- diameter10 mm
- Divergence 0.5 mrad (half-angle)
-30% of the beam

Compression

- Compression ➡ Need to increase the brightness
- compression of a fast beam (v>100 m.s-1) is not standard
- Simulations have been started

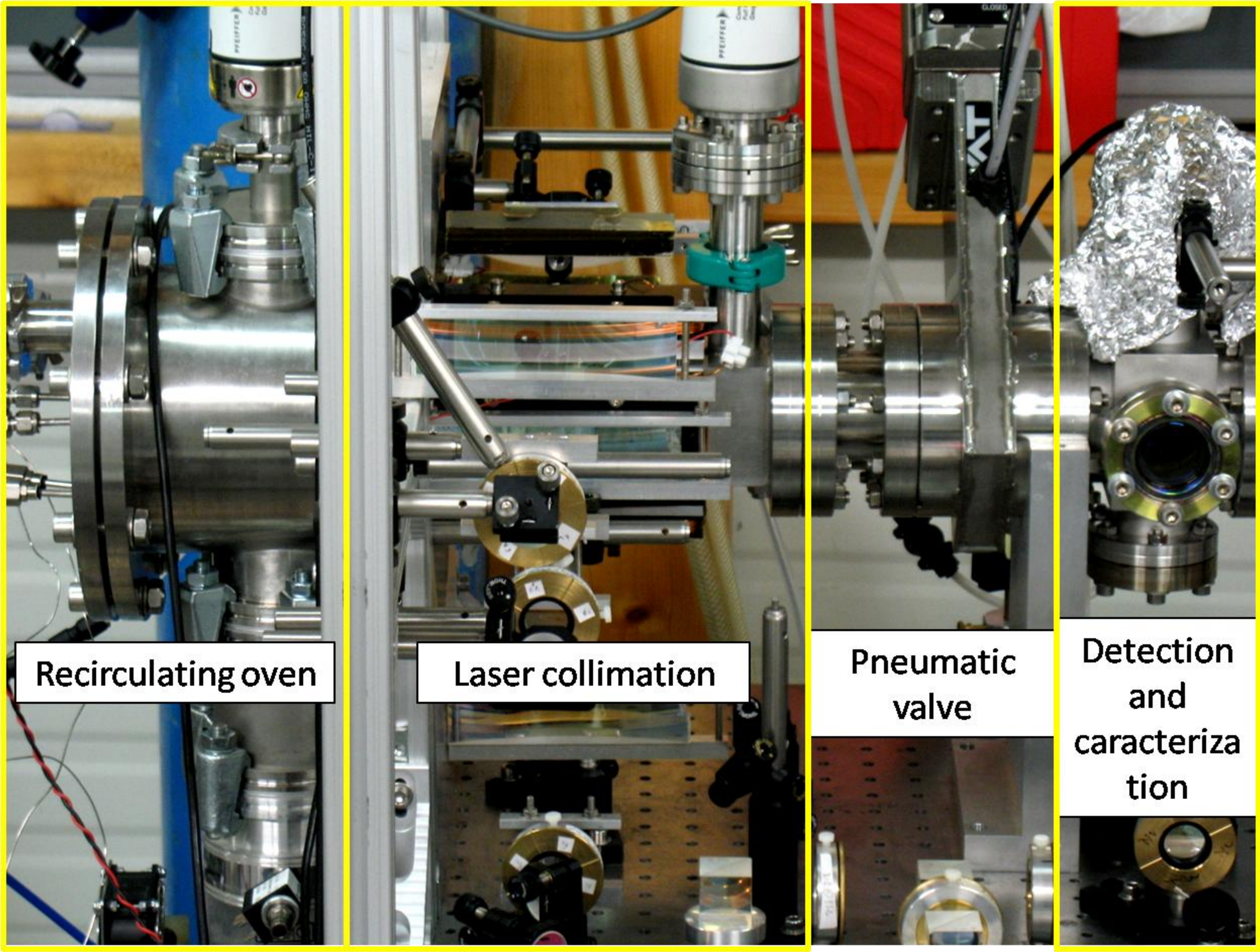


- Jouda Djemaa, thesis LAC (1994)
- done at 170m.s^{-1}
- laser + magnet on 3 cm
  ➡ Brightness x300

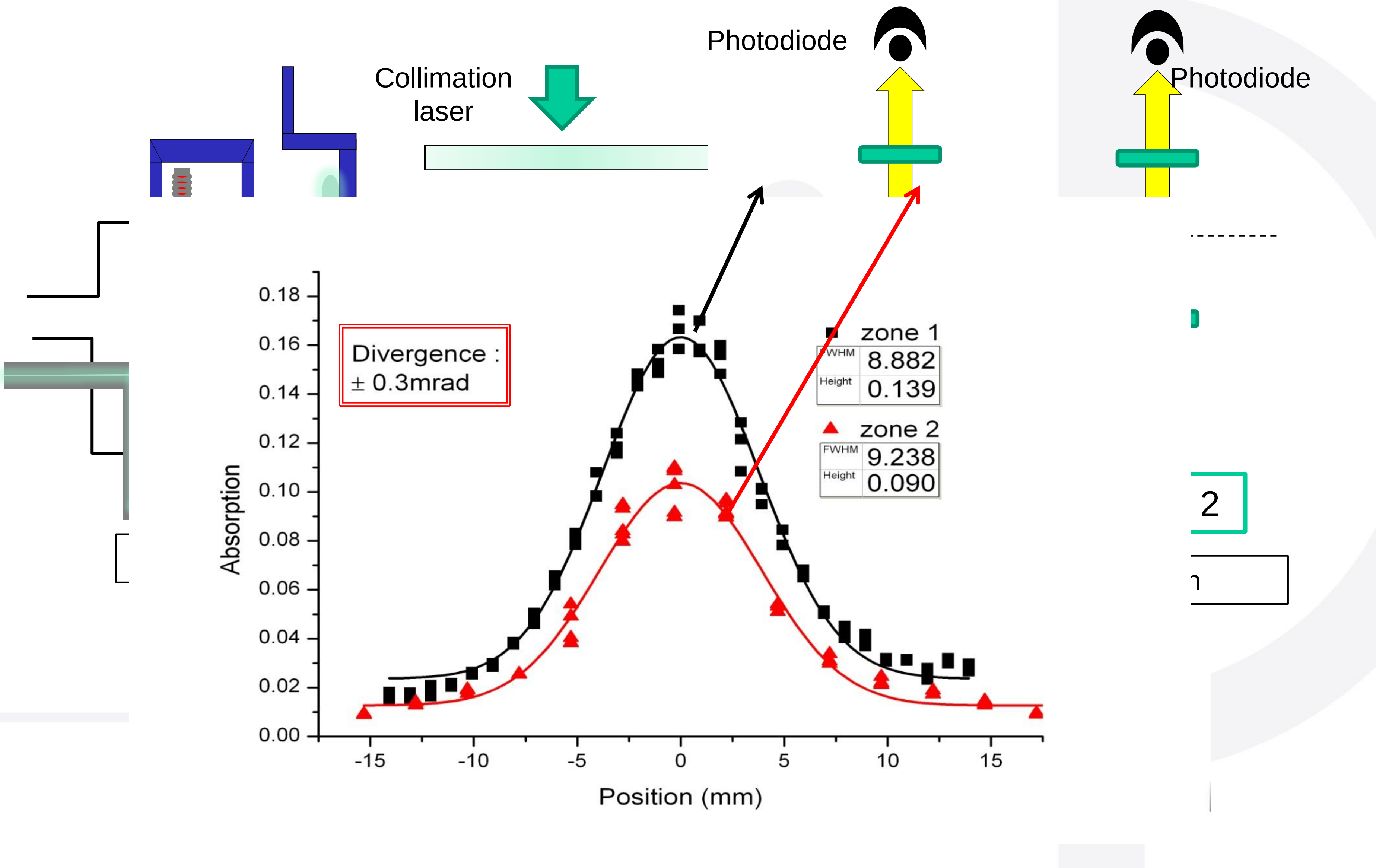
Compression density limit 10^{11} at. cm^{-3}

H. P. Metcalf and P. Van der Straten, *Laser cooling and trapping*, 1999

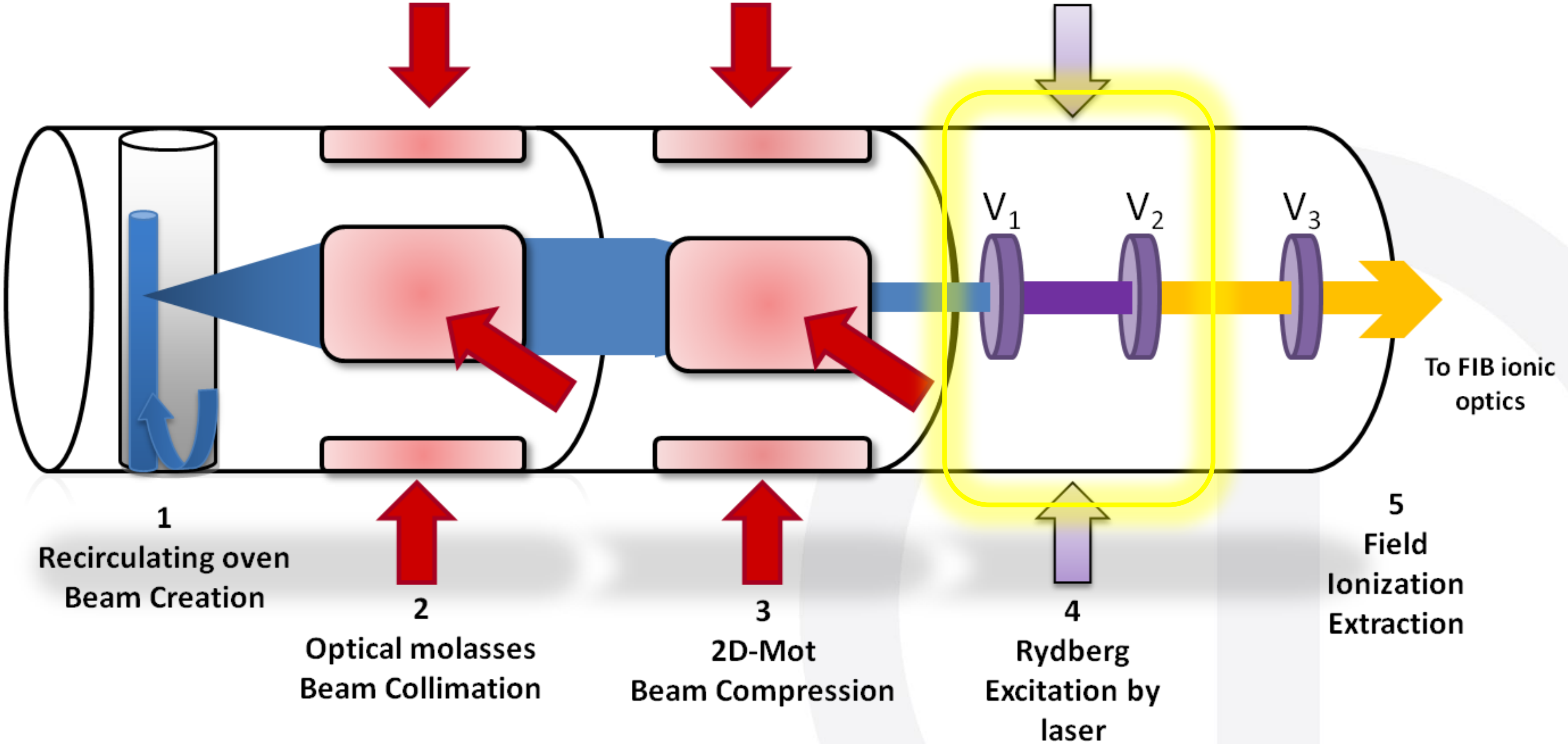
Experimental setup



Characterisation and divergence

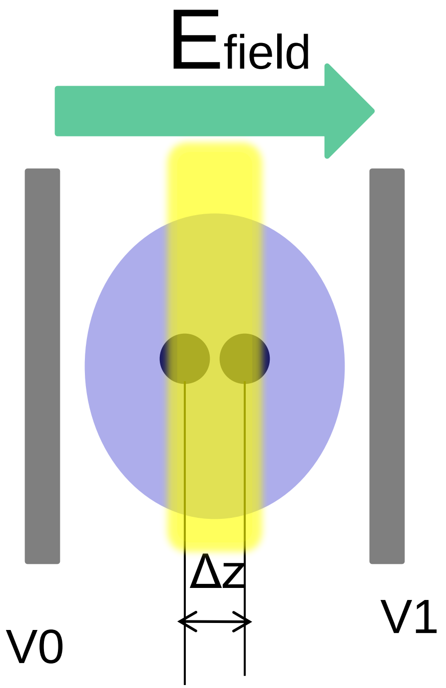


Our source



	1	2	3	4-5
Average longitudinale speed(m/s)	300	300	300	300
Divergence (mrad)	40	<0.3	0.5	0.5
Flux (at/s)	10^{13}	3.10^{12}	5.10^{13}	2.10^{10}
Diameter(mm)	2	10	1.5	0.1

alternative to photoionisation



$\Delta E = E\, \Delta z$

To avoid coulomb effects
➡ E_{field}>1kV/cm
With a waist ~10µm
➡ ΔE=1V

<u>Limits of photoionisation</u>

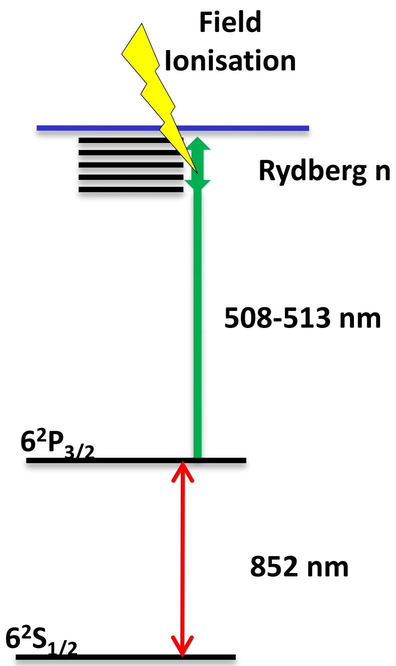
ΔE depends to electric field E

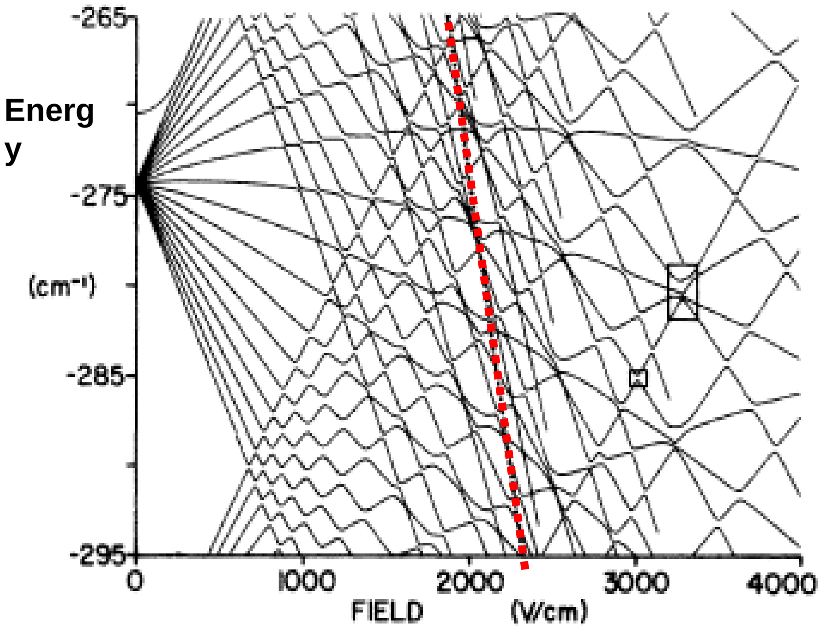
<u>Idea</u>

Ionise atoms in a small area with well control field

➡ Rydberg atoms

Rydberg excitation and field ionisation

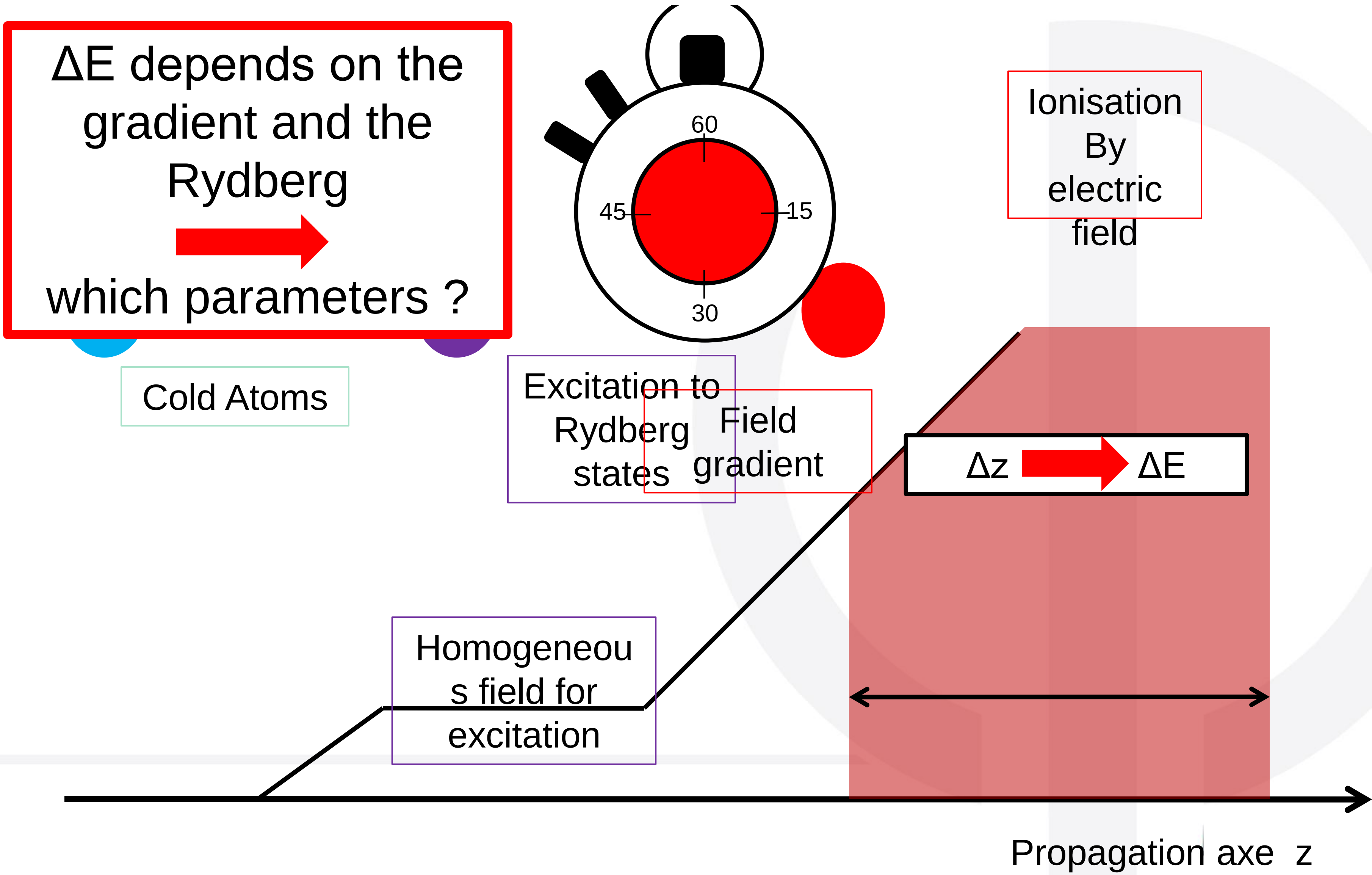




Classical field ionisation $E = \frac{1}{16n^4}$

- **Excitation in homogeneous field**
- **Excitation under the ionisation limit**
- **Ionisation in a field gradient**

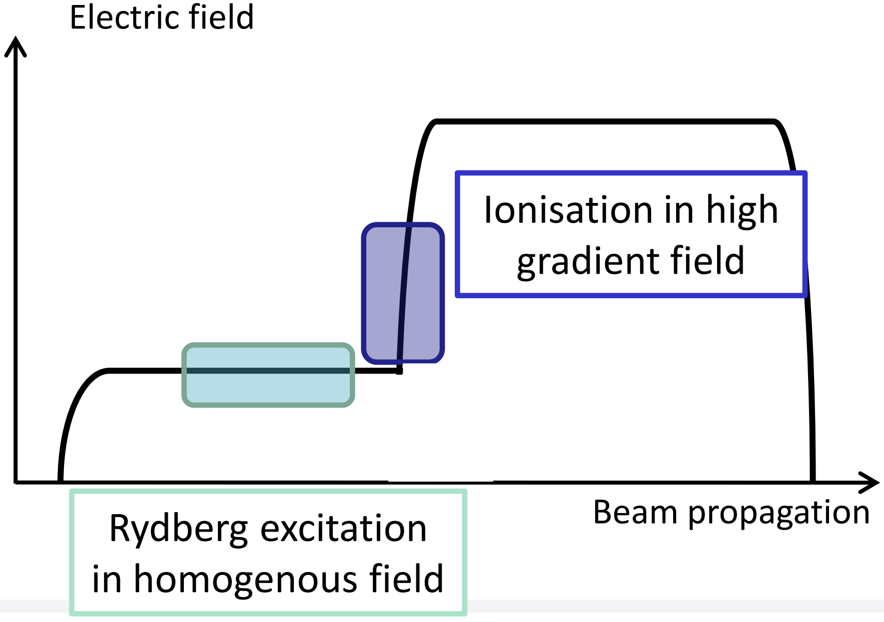
Rydberg excitation and field ionisation



Choice of the parameters

Good compromise

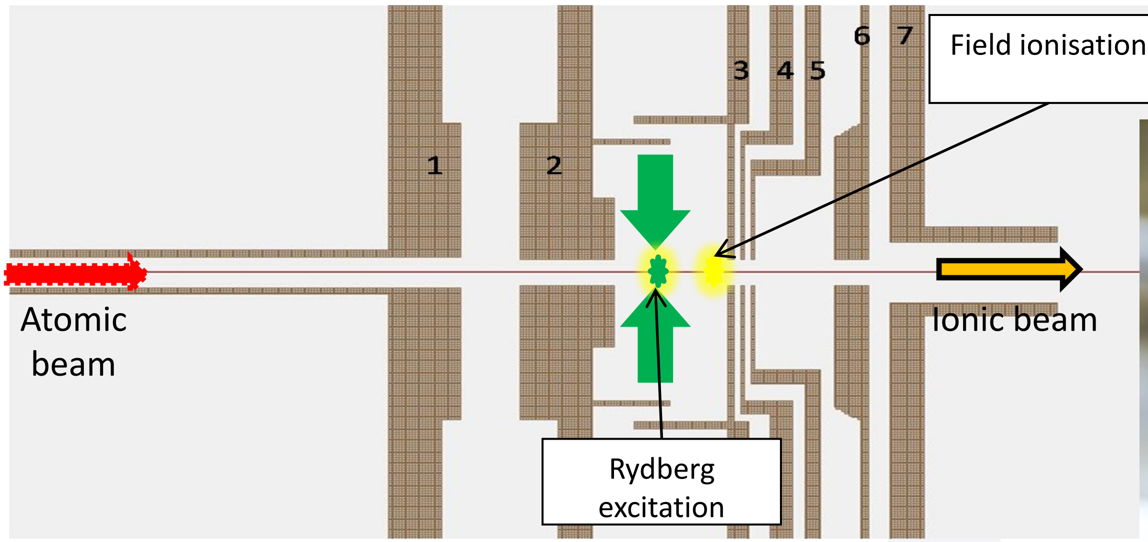
Rydberg n≈30

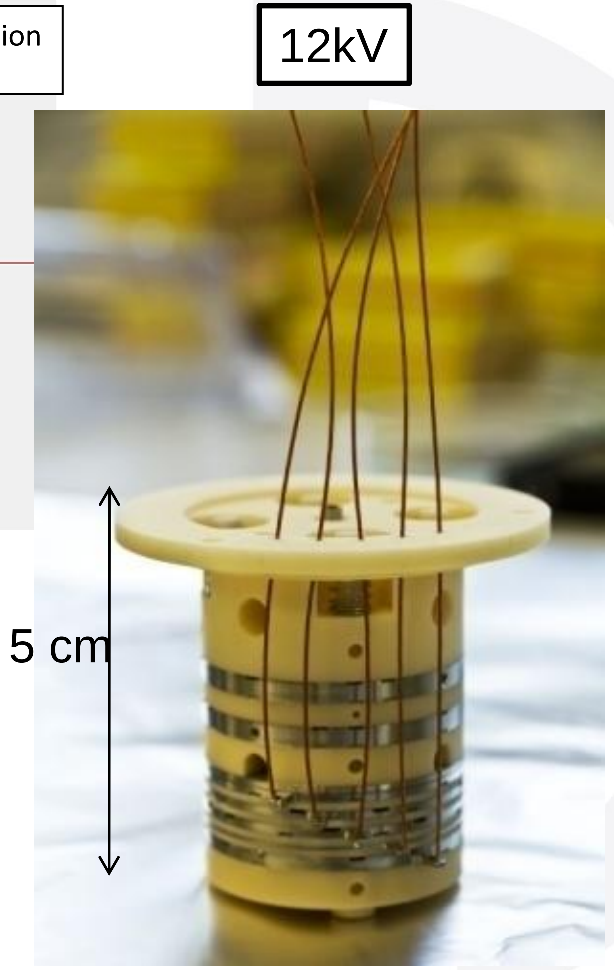


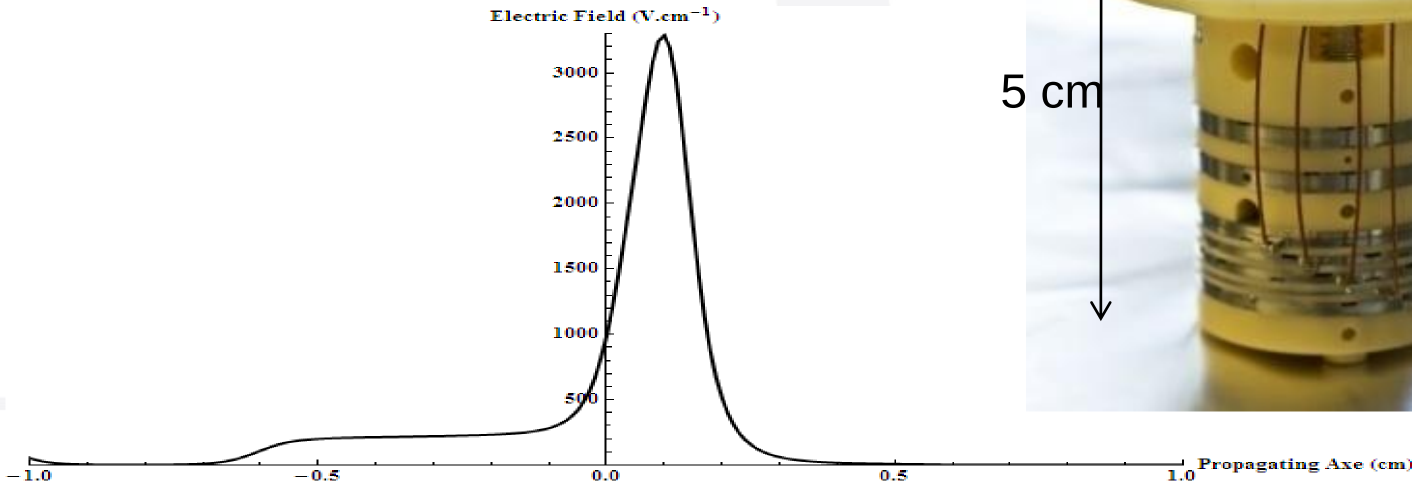
Constraints on the field

- Homogeneous field for the excitation part <100 V/cm/cm to avoid Stark shift
- Ionisation at 1000V/cm ($n \approx 30$)
- Ionisation not further than 3 mm of the excitation area (Rydberg lifetime)
- Gradient field for ionisation: min 1000V/cm/cm – max 30.000V/cm/cm

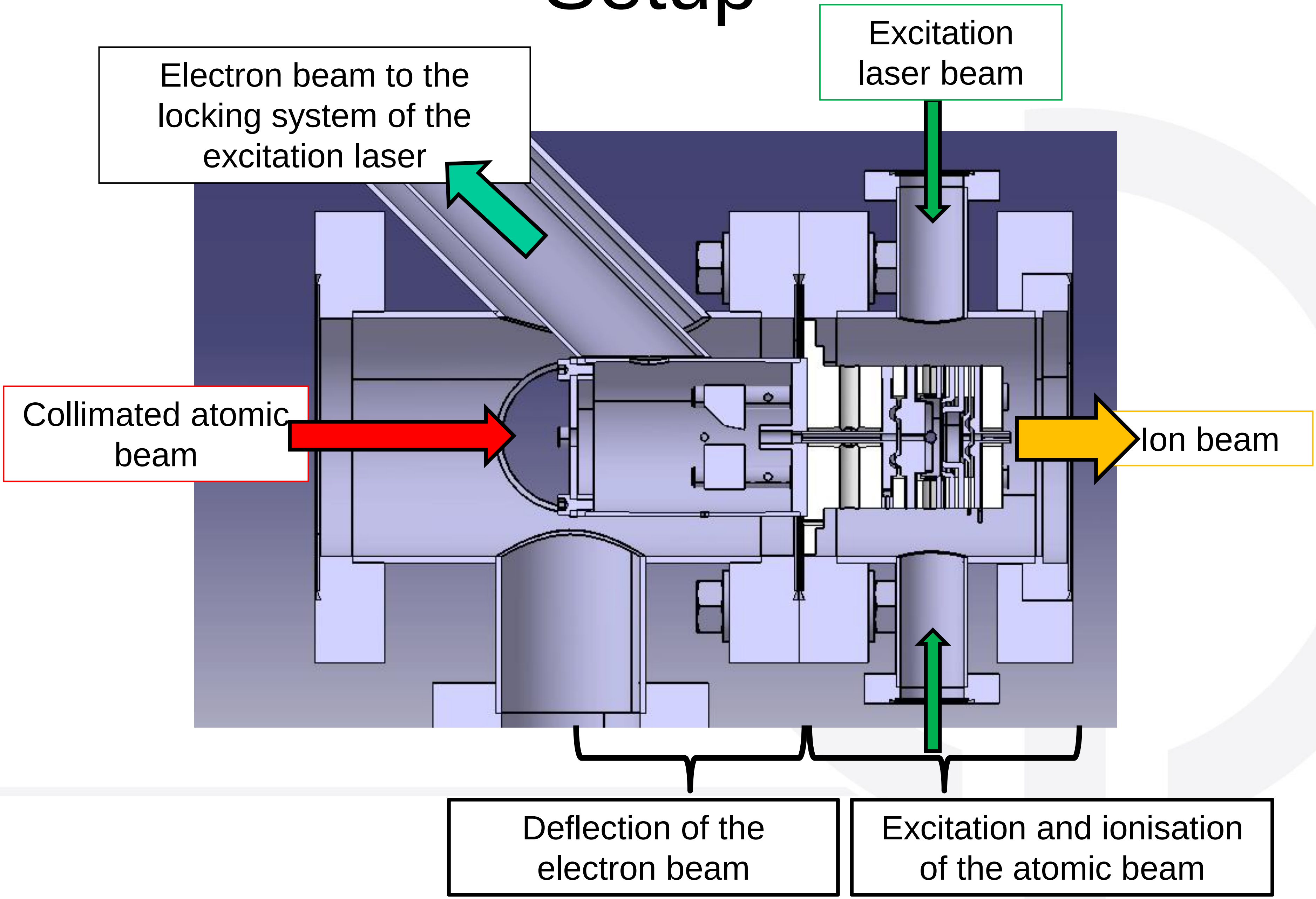
Excitation-Ionisation module





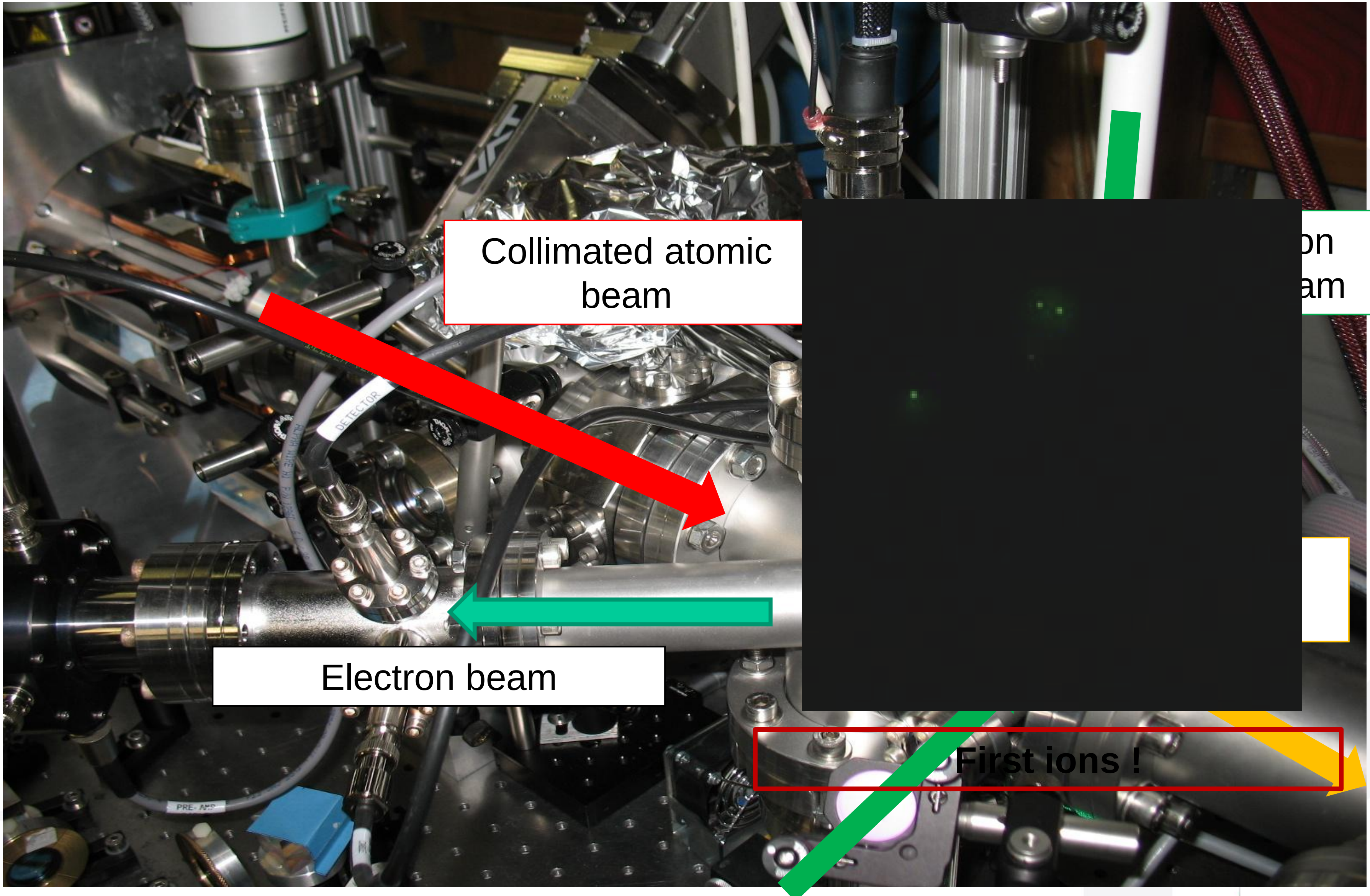


Setup

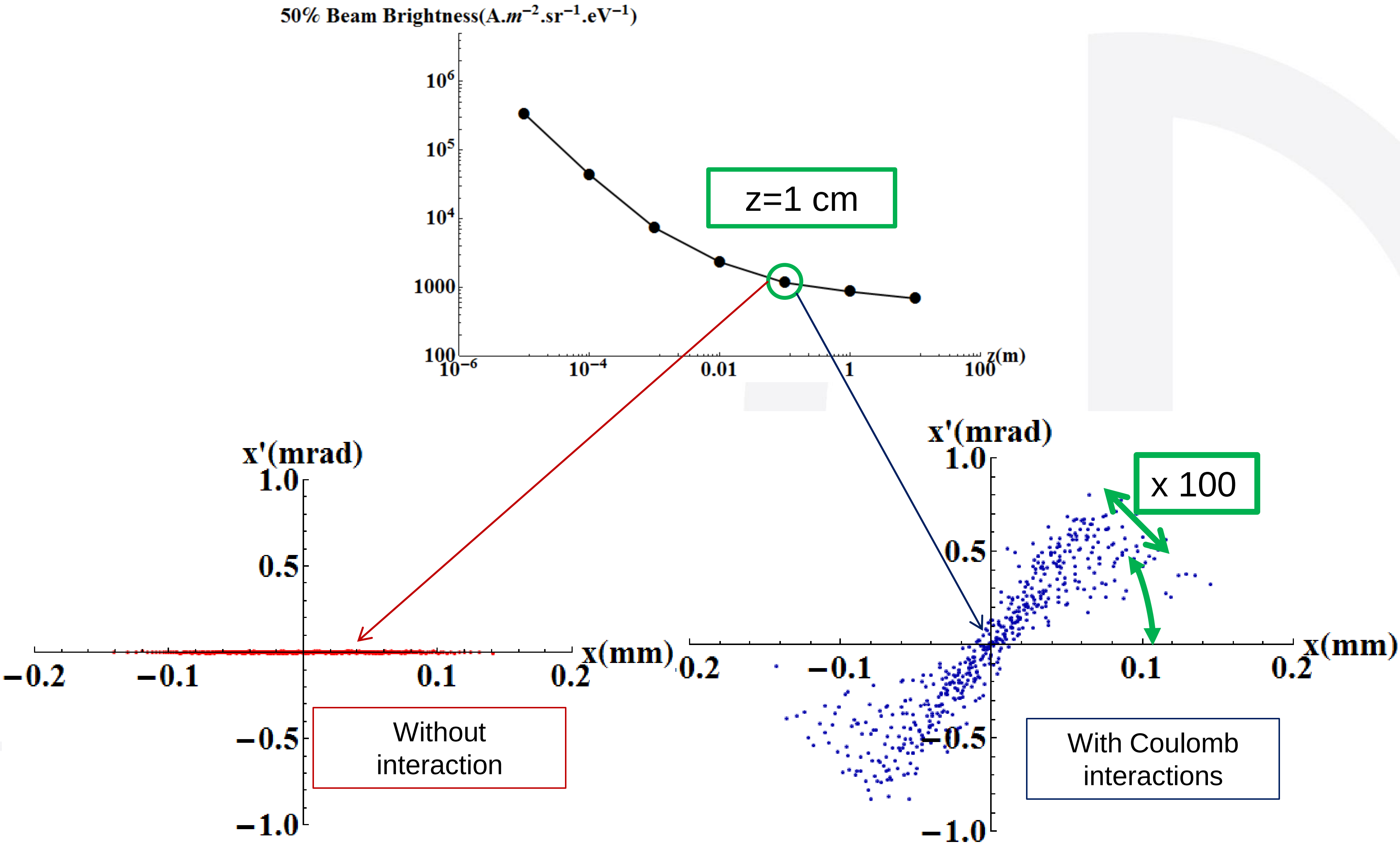


Electron beam to the locking system of the excitation laser
Excitation laser beam
Collimated atomic beam
Ion beam
Deflection of the electron beam
Excitation and ionisation of the atomic beam

Setup

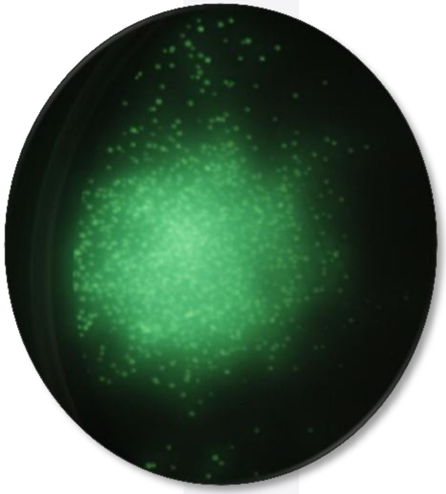


Coulomb effects and propagation of the beam



Conclusions

- Realisation of a continuous ionic beam from cold atoms
  - Recirculating oven ✓ - flux de 10^{13} at/s
  - Laser collimation ✓ - divergence < 0.3 mrad
  - Excitation/Ionisation ✓ - first ions
- To be done
  - Compression of the atomic beam
  - New oven without wick
  - Improve the ions signal
  - Coupling with FIB optics
- theory
  - Rydberg ionisation in electric field
  - Coulomb effects
- Other possibilities
  - Electron beam
  - Pulse source
  - ...



Acknowledgement

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- Andrea Fioretti (Pisa)

Collaboration

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SEVENTH FRAMEWORK PROGRAMME

ORSAY GROUP