Development of laser stripping at the SNS

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On behalf of the SNS laser stripping team

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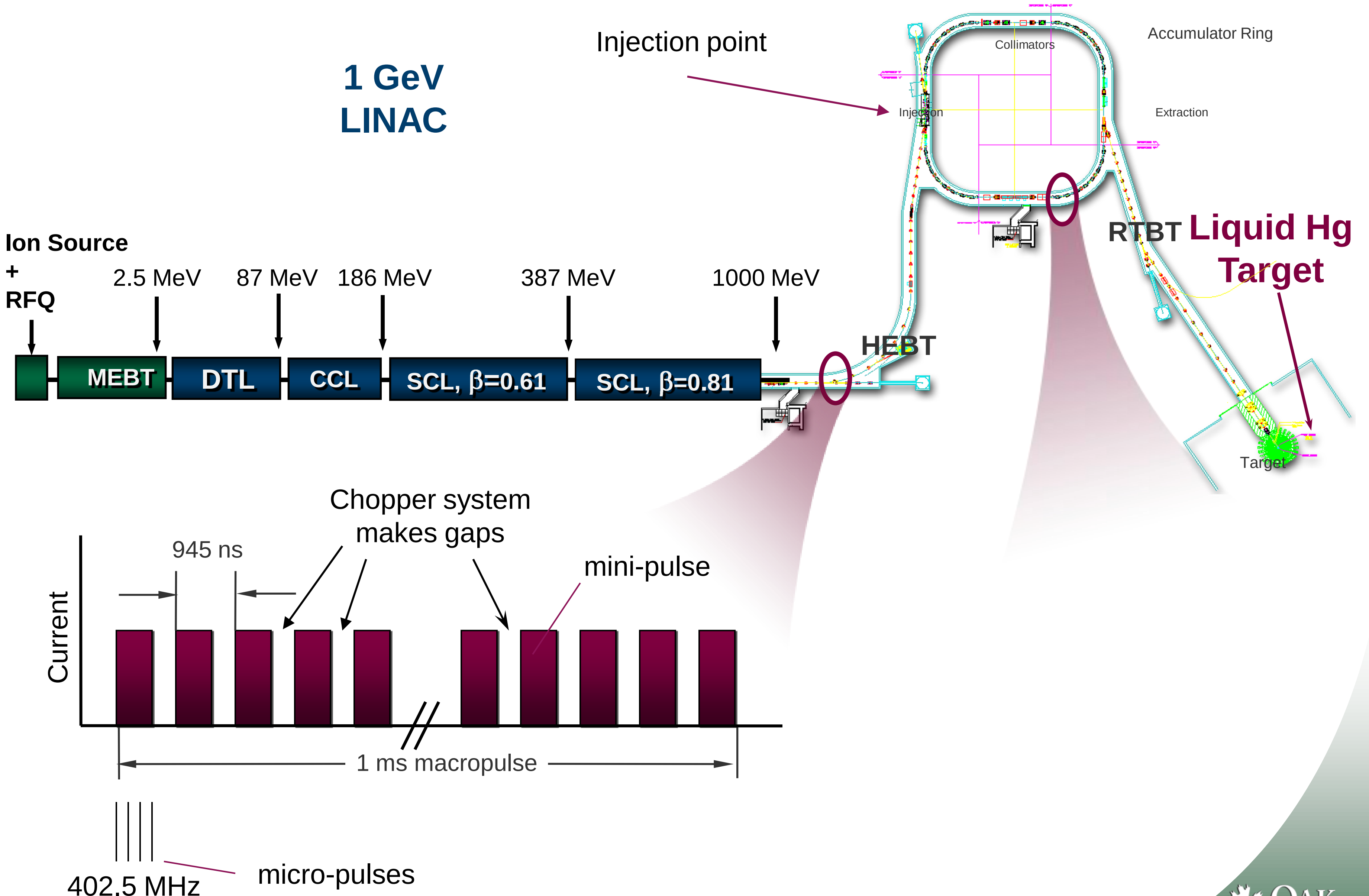
Outline

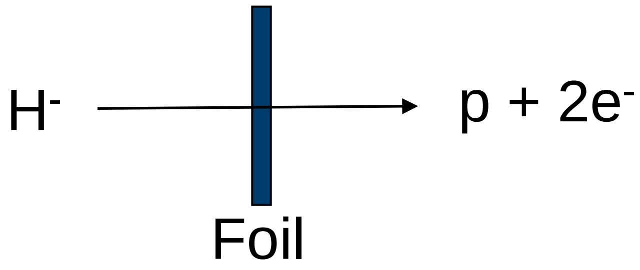
- History of laser stripping
- Proof of principle experiment
- Physical model
- Proof of practicity experiment
- Experimental studies
- Future plans and ideas for SNS and other projects

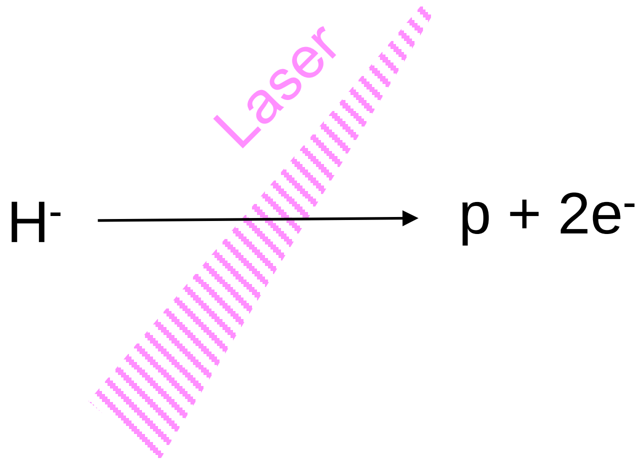
SNS Accelerator Complex



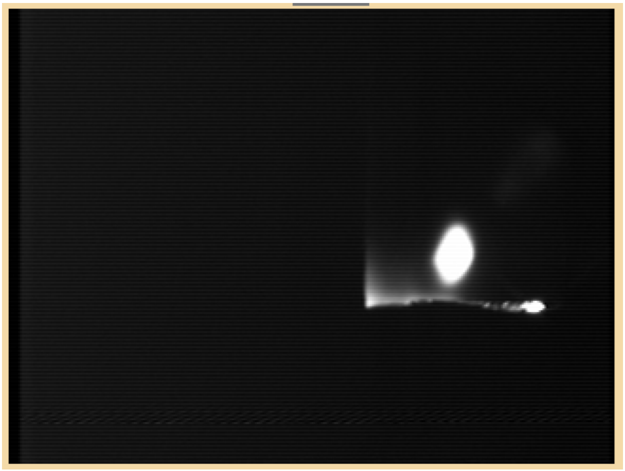
Goals

$H^- \rightarrow p + 2e^-$





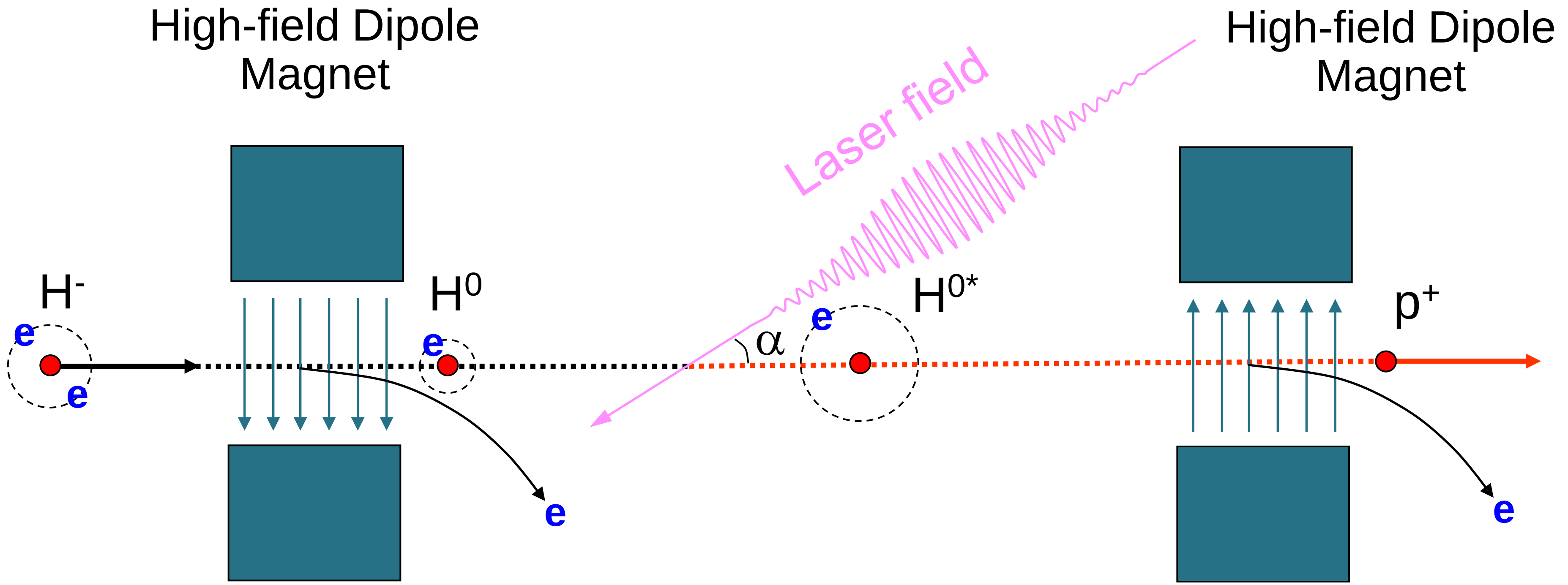
- **Replacement of stripping foil by laser assistant stripping**



Foil (Beam on)

Three-step laser stripping scheme

V. Danilov (2003)



Step 1: Lorentz Stripping

$H^- \rightarrow H^0 + e^-$

Step 2: Resonant laser Excitation

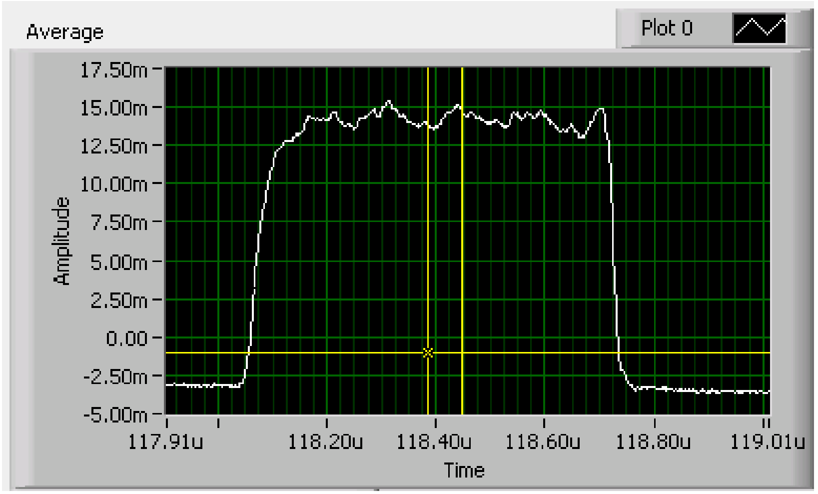
$H^0\ (n=1) + \gamma \rightarrow H^{0*}\ (n=3)$

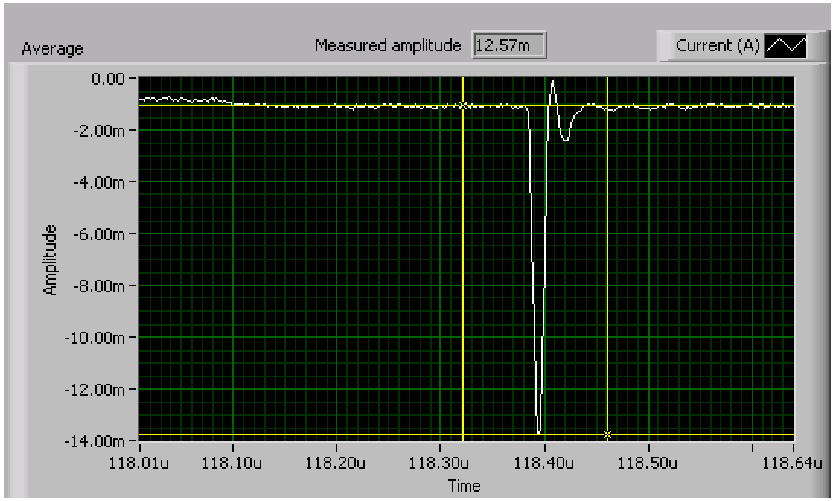
Step 3: Lorentz Stripping

$H^{0*} \rightarrow p + e^-$

Proof of principle experiment (2006)

mini-pulse

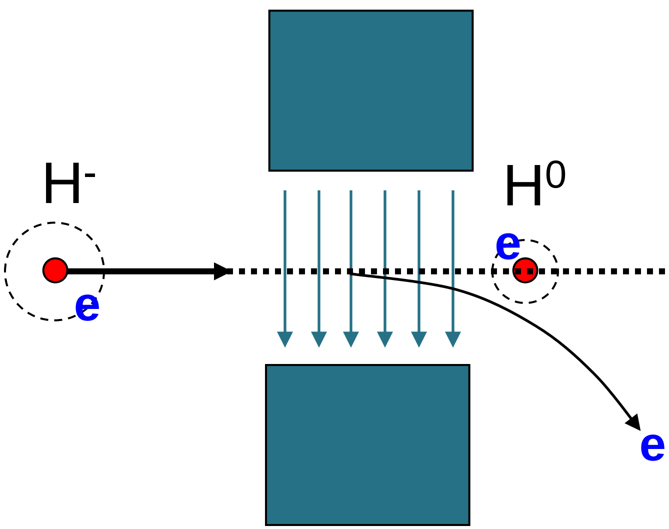




The maximal achieved efficiency: 0.85±0.1 (1st run) and 0.9±0.05 (2nd run)
Stripping time: about 10 ns

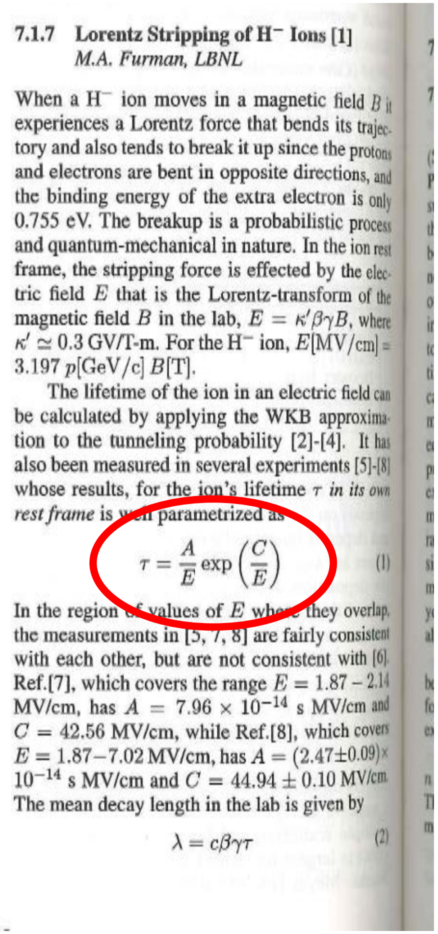
Theory of the Laser Stripping

High-field Dipole Magnet



Step 1: Lorentz Stripping

$H^- \rightarrow H^0 + e^-$



7.1.7 Lorentz Stripping of H^- Ions [1]
M.A. Furman, LBNL

When a H^- ion moves in a magnetic field B it experiences a Lorentz force that bends its trajectory and also tends to break it up since the protons and electrons are bent in opposite directions, and the binding energy of the extra electron is only 0.755 eV. The breakup is a probabilistic process and quantum-mechanical in nature. In the ion rest frame, the stripping force is effected by the electric field E that is the Lorentz-transform of the magnetic field B in the lab, $E = \kappa' \beta\gamma B$, where $\kappa' \simeq 0.3$ GV/T-m. For the H^- ion, E[MV/cm] = $3.197\ p$[GeV/c] B[T].

The lifetime of the ion in an electric field can be calculated by applying the WKB approximation to the tunneling probability [2]-[4]. It has also been measured in several experiments [5]-[8] whose results, for the ion's lifetime τ *in its own rest frame* is well parametrized as

$$\tau = \frac{A}{E} \exp\left(\frac{C}{E}\right) \qquad (1)$$

In the region of values of E where they overlap, the measurements in [5, 7, 8] are fairly consistent with each other, but are not consistent with [6]. Ref.[7], which covers the range $E = 1.87 - 2.14$ MV/cm, has $A = 7.96 \times 10^{-14}$ s MV/cm and $C = 42.56$ MV/cm, while Ref.[8], which covers $E = 1.87 - 7.02$ MV/cm, has $A = (2.47 \pm 0.09) \times 10^{-14}$ s MV/cm and $C = 44.94 \pm 0.10$ MV/cm. The mean decay length in the lab is given by

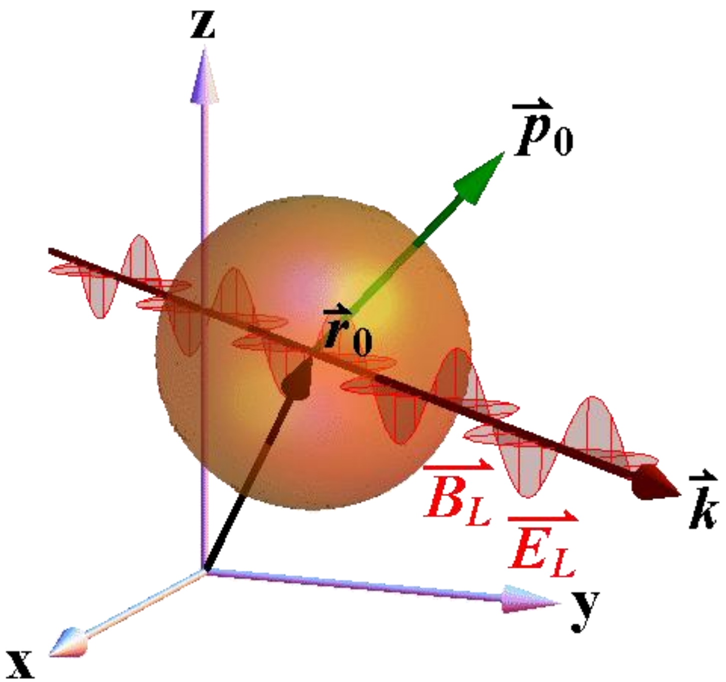
$$\lambda = c\beta\gamma\tau \qquad (2)$$

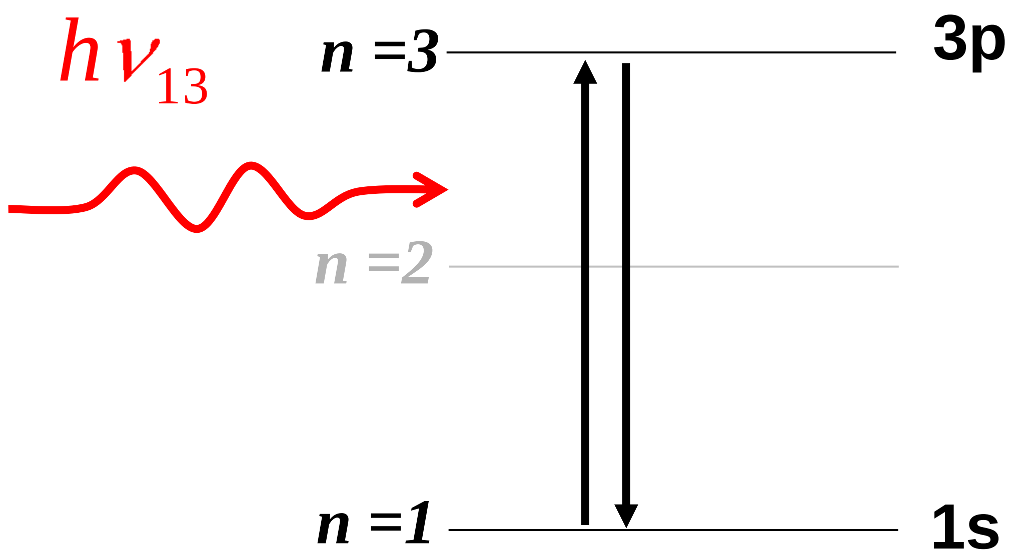
Two level atom (Schrodinger equation)

The model is valid only for E=B=0 and linear polarized laser field

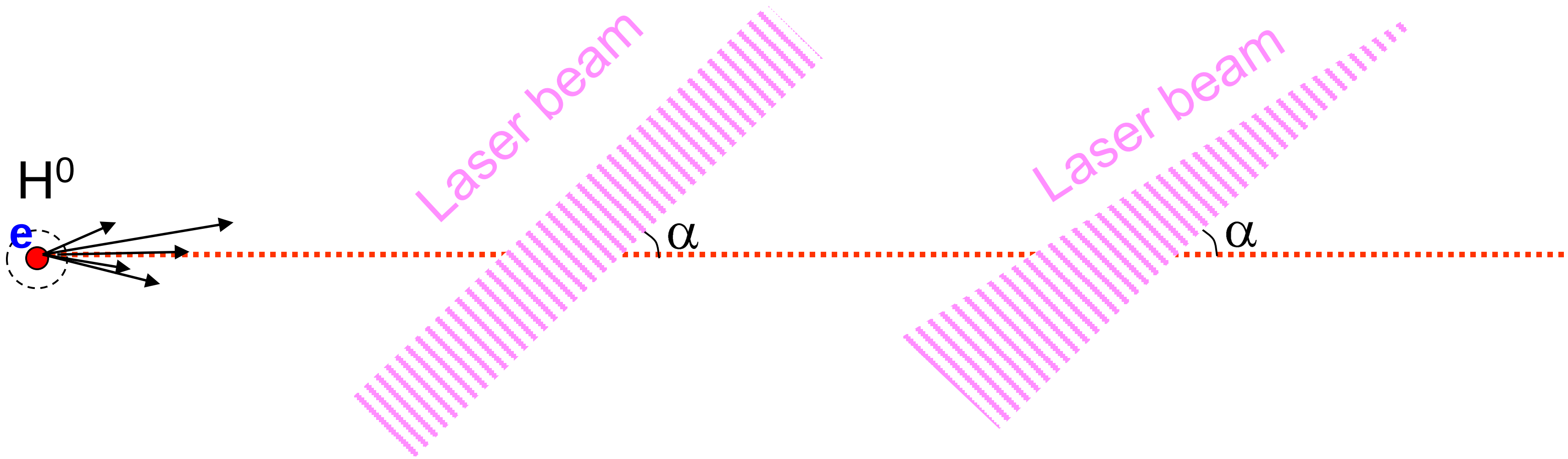
$$i\hbar \frac{\partial \Psi}{\partial t} = \hat{H}(\vec{E}_L)\Psi$$

$$\begin{cases} \dot{c}_1 = c_3 s_{13}(E_L) \\ \dot{c}_3 = c_1 s_{31}(E_L) \end{cases}$$





First way to compensate energy spread



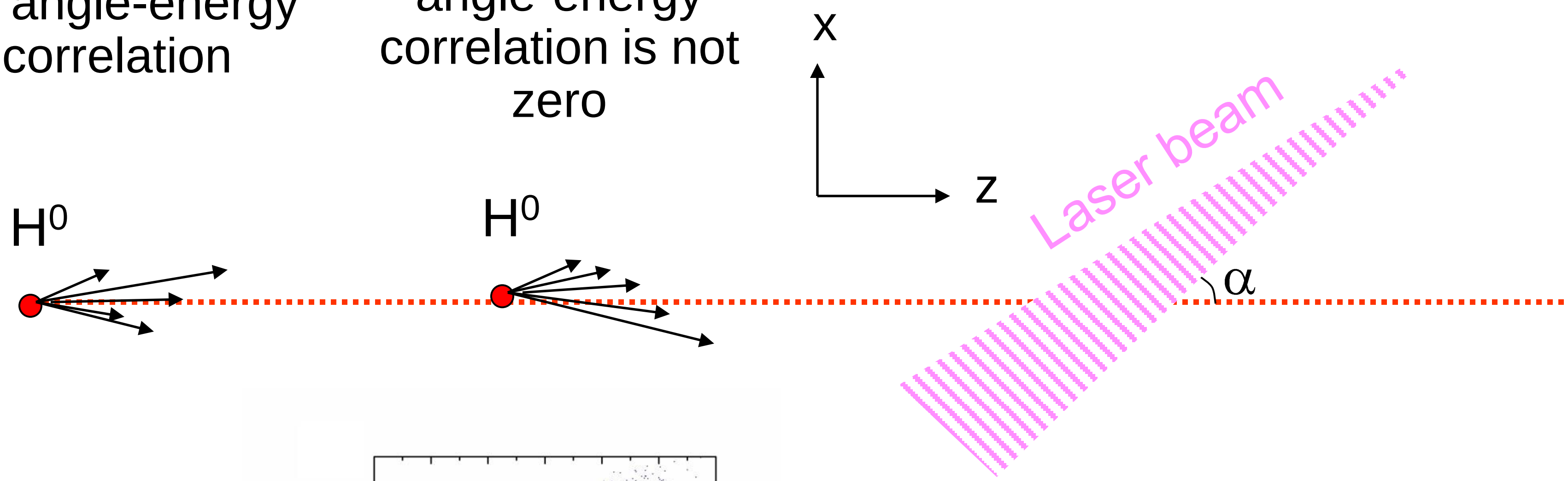
Bad laser optics scheme

Good laser optics

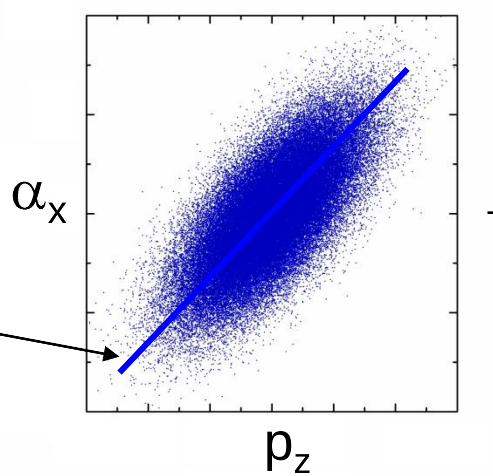
Second way to compensate energy spread

No angle-energy correlation

angle-energy correlation is not zero



Perfect correlation

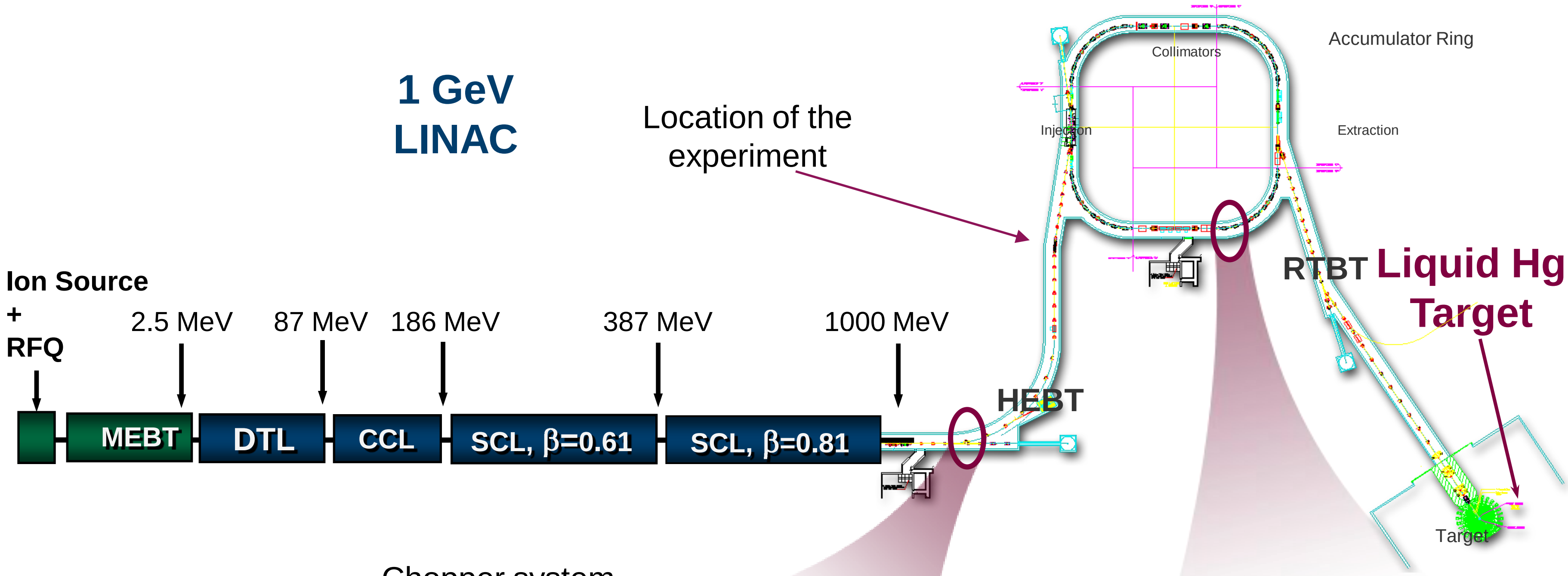


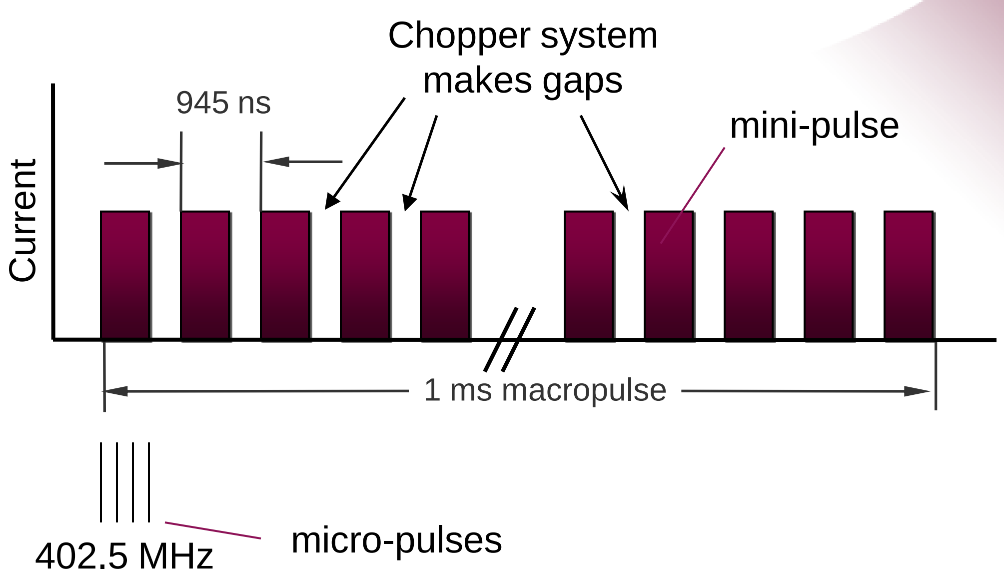
Necessary correlation is given by dispersion function

D_x'=2.6 for T=1 GeV beam

Proof of plasticity experiment

SNS Accelerator Complex

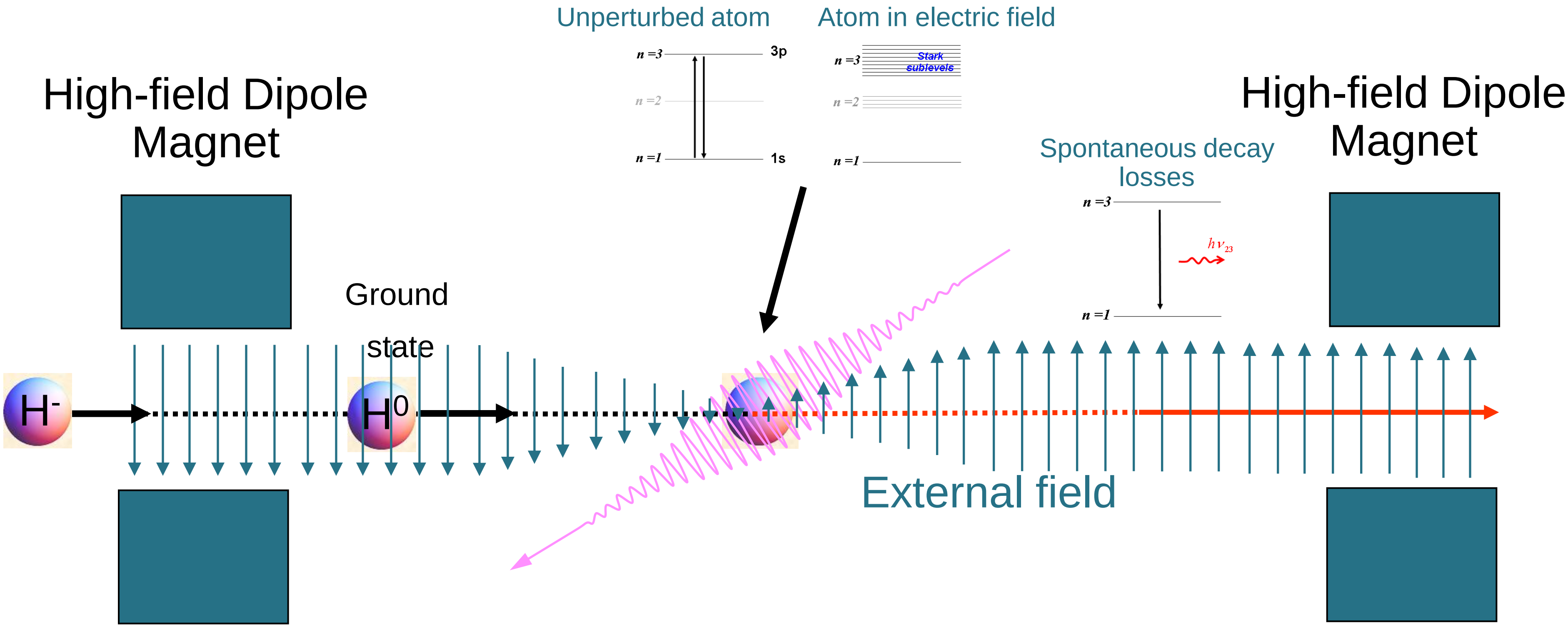




Proof of principles
Stripping time appr. 10 ns

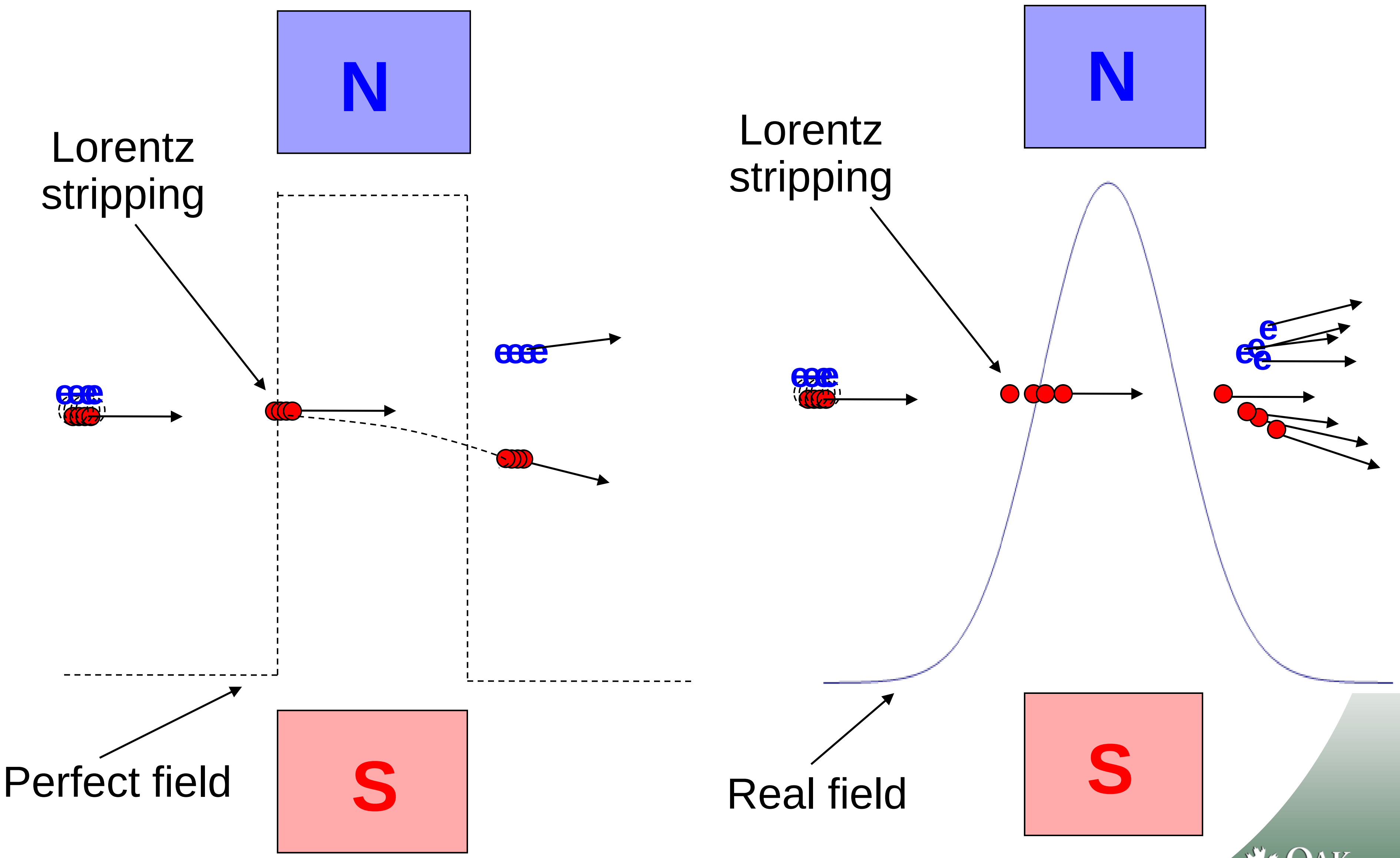
Proof of practicity
Stripping time appr. 1 us

Advanced physical model



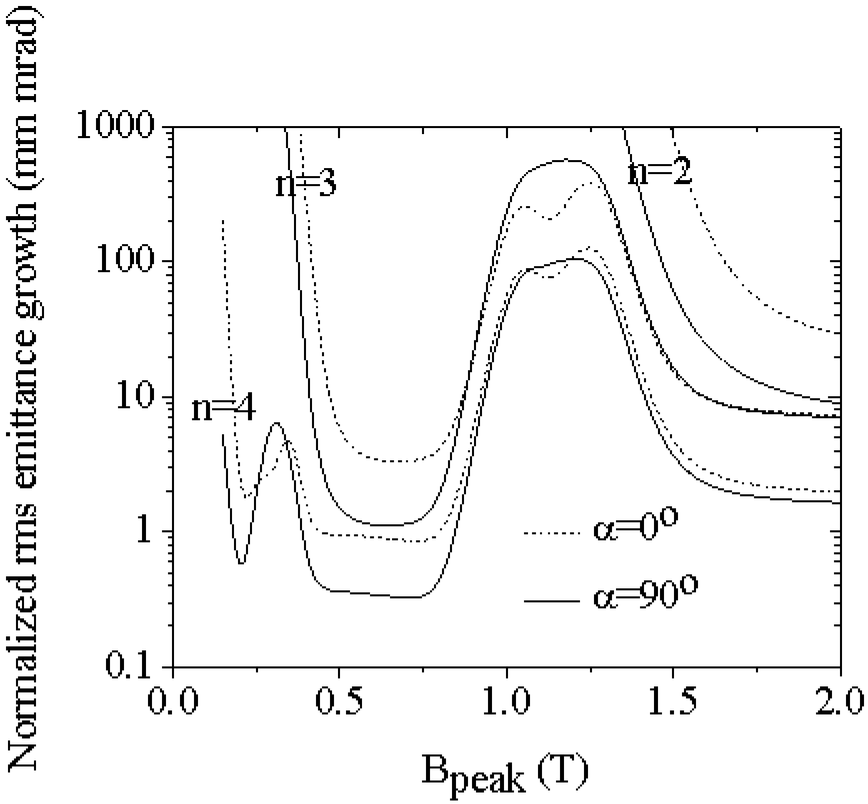
- **Stark effect at the interaction point**
- **Spontaneous decay losses**
- **Lorentz stripping of H^0 excited beam**

Lorentz stripping of H^0 excited beam in the fringe magnetic field



Emittance growth at the fringe field

Fringe field: $$F(s) = \frac{B}{1 + \exp[a_1 + a_2(\frac{s}{D}) + a_3(\frac{s}{D})^2 + a_4(\frac{s}{D})^3 + a_5(\frac{s}{D})^4 + a_6(\frac{s}{D})^5]}$$



T=4 GeV

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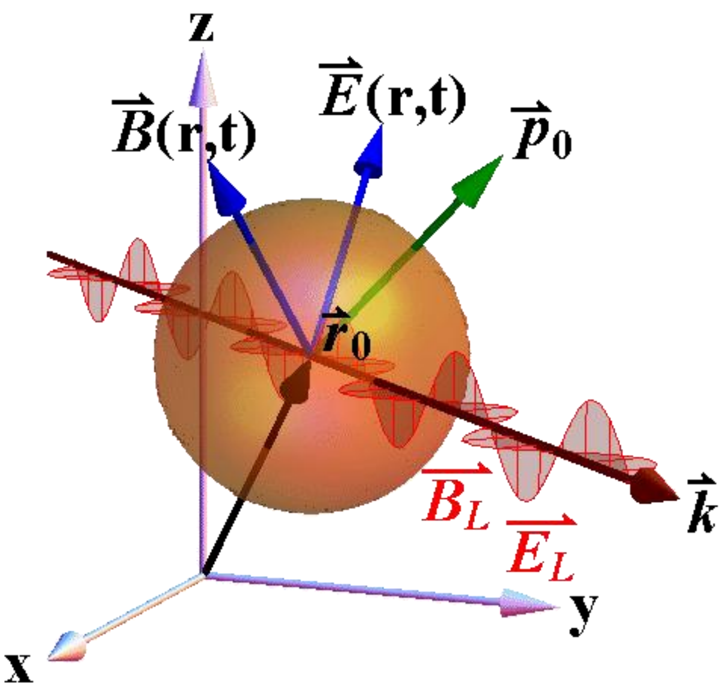
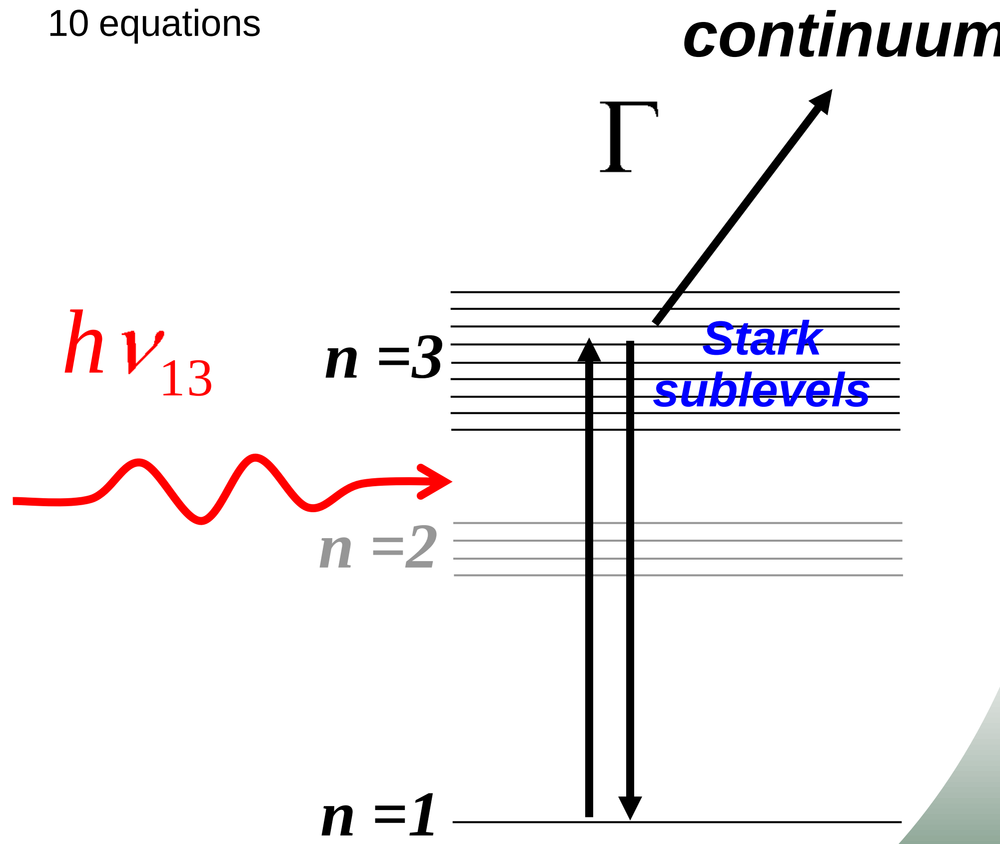
Schrödinger equation approach

Spontaneous decay can not be taken into account

$$i\hbar\frac{\partial\Psi}{\partial t}=\hat{H}(\vec{E},\vec{E}_L)\Psi \quad\rightarrow\quad \dot{c}_m(t)=\sum_{n=1}^{N}c_n(t)S_{mn}(t) \qquad N=1^2+3^2=10$$

10 equations



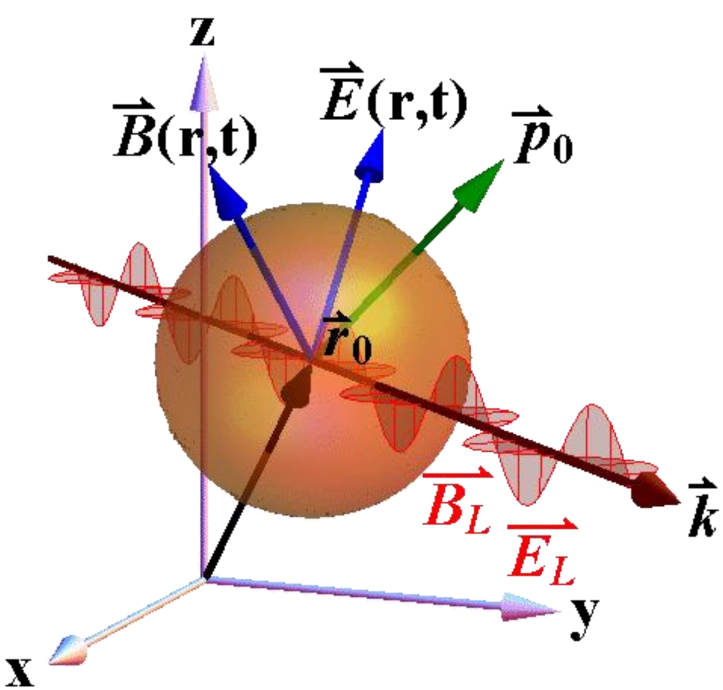


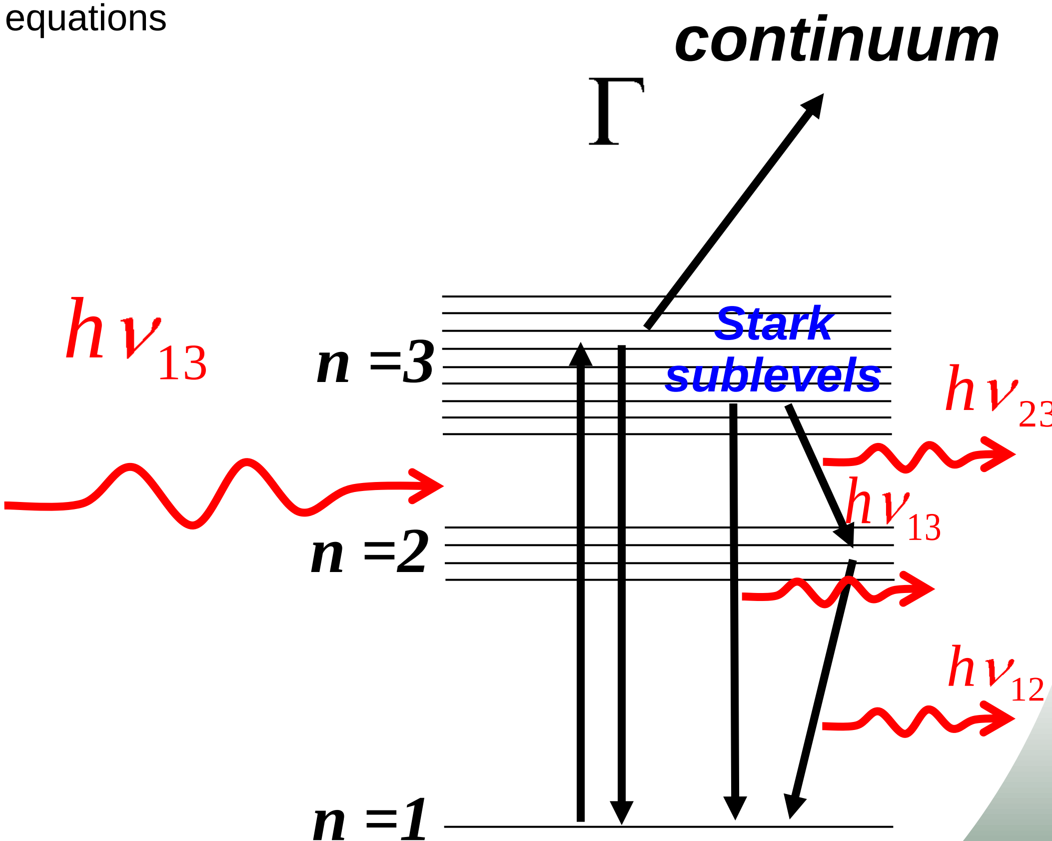
Density matrix approach

Everything can be taken into account

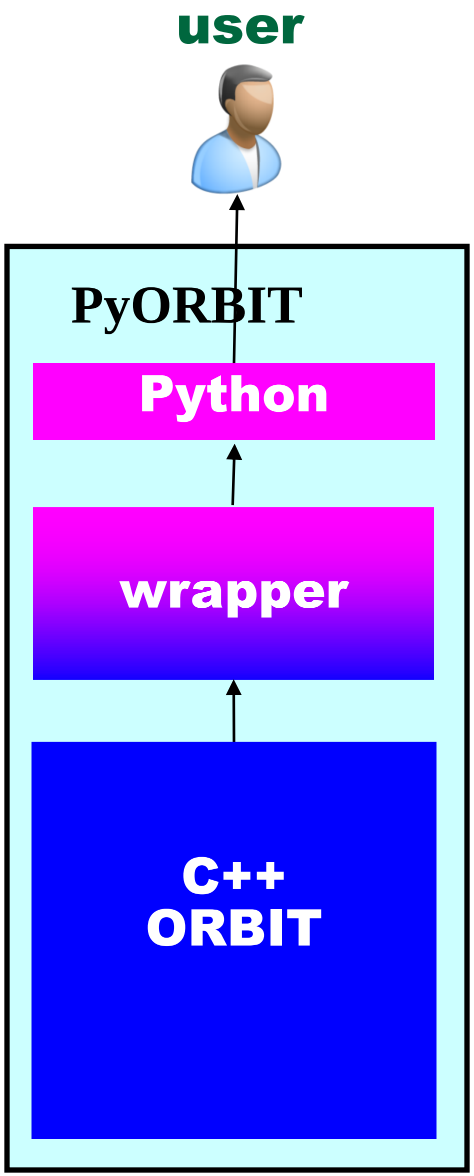
Master equation $\rightarrow$ $\dot{\rho}_{nm}(t) = D[\rho]$ $m,n = 1, N$ $N = 1^2 + 2^2 + 3^2$

196 equations

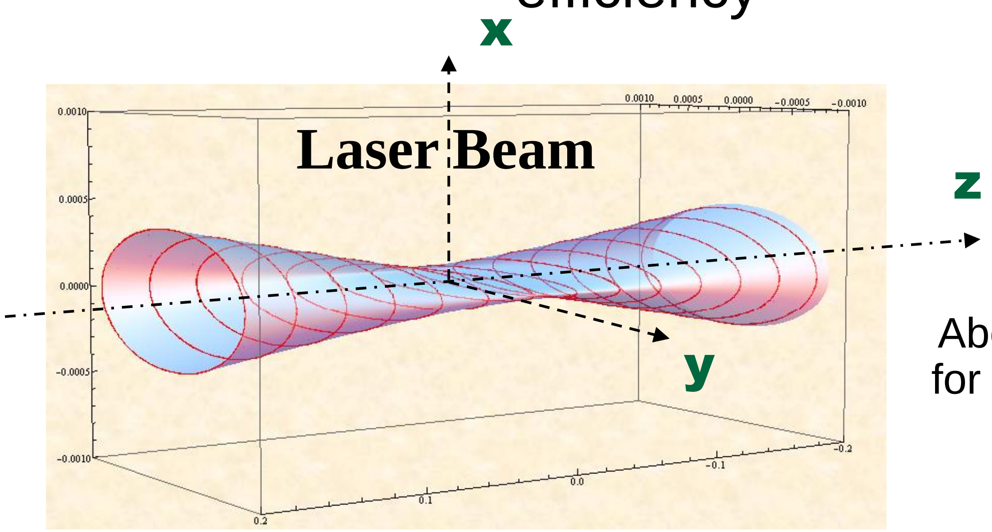




Computer application for laser stripping

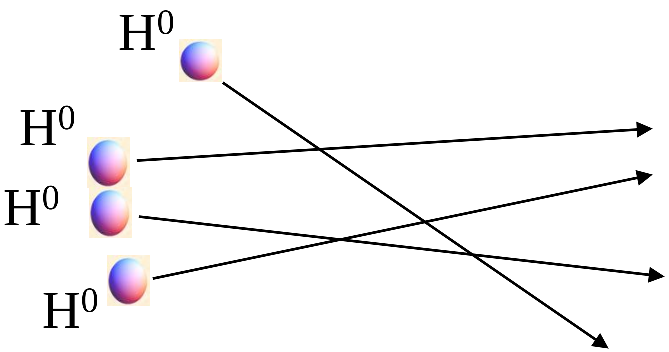


We can optimize parameters of laser beam and H^- beam for better stripping efficiency



About 5 parameters for description of the laser beam

Hydrogen Beam



Emittance parameters for description of the H^0 beam

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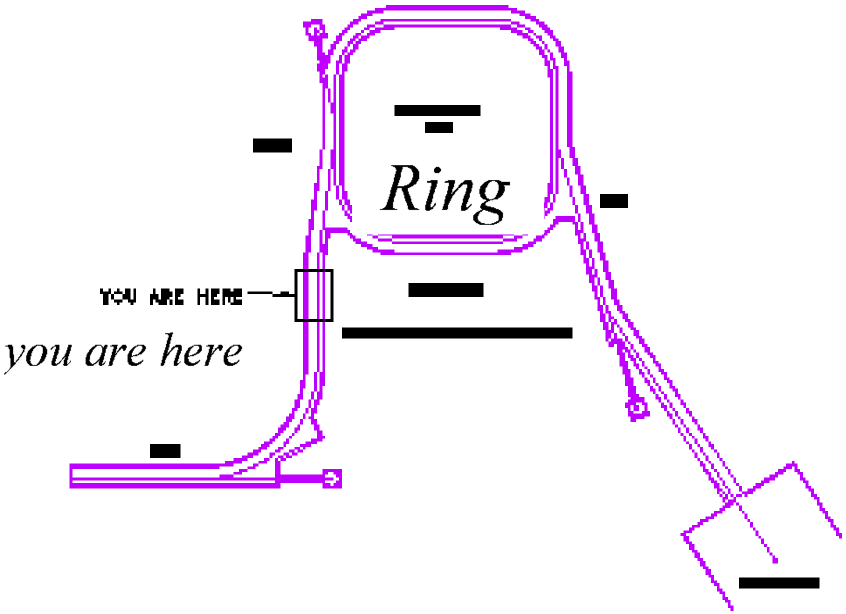
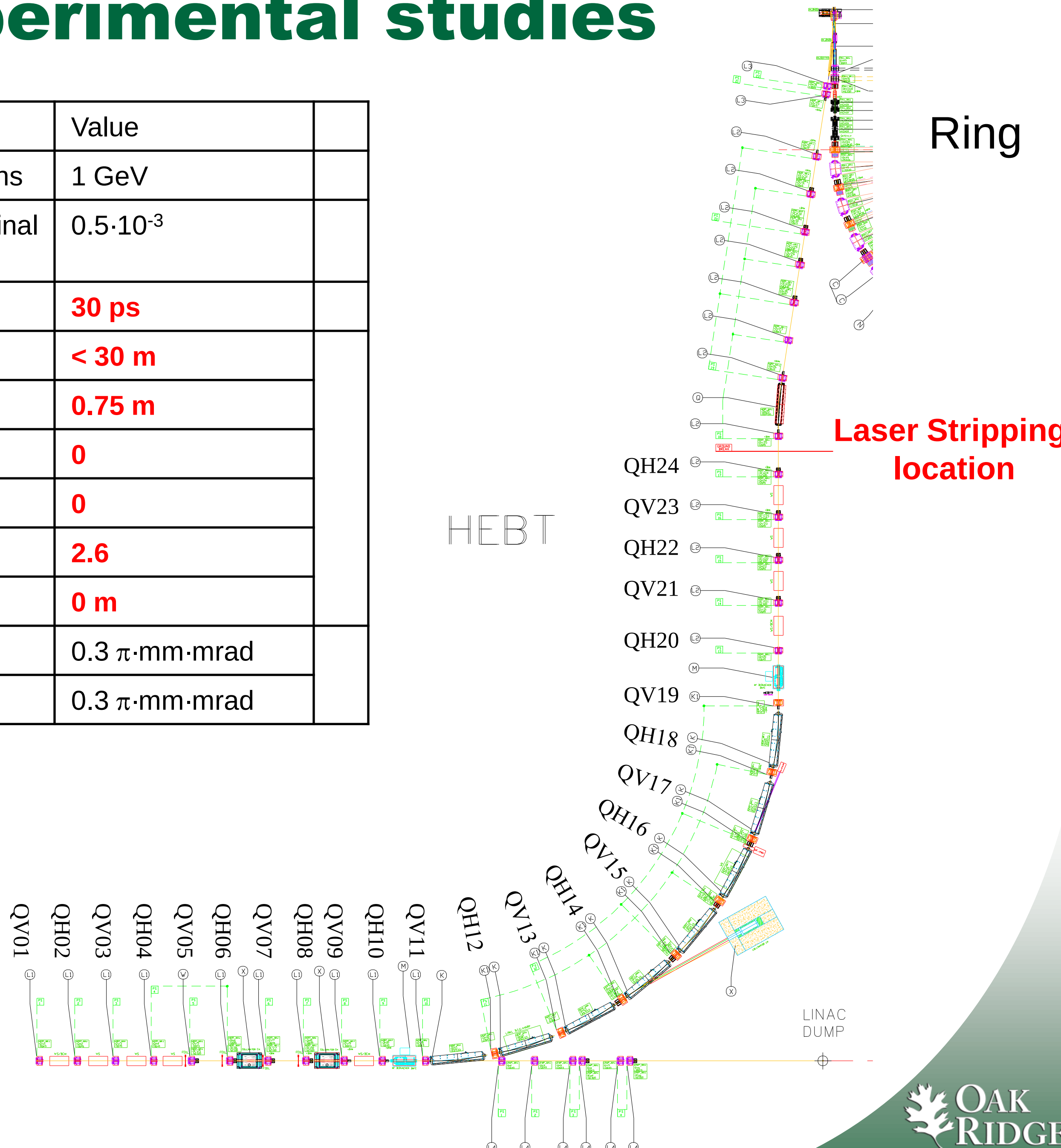
Location for the new experiment



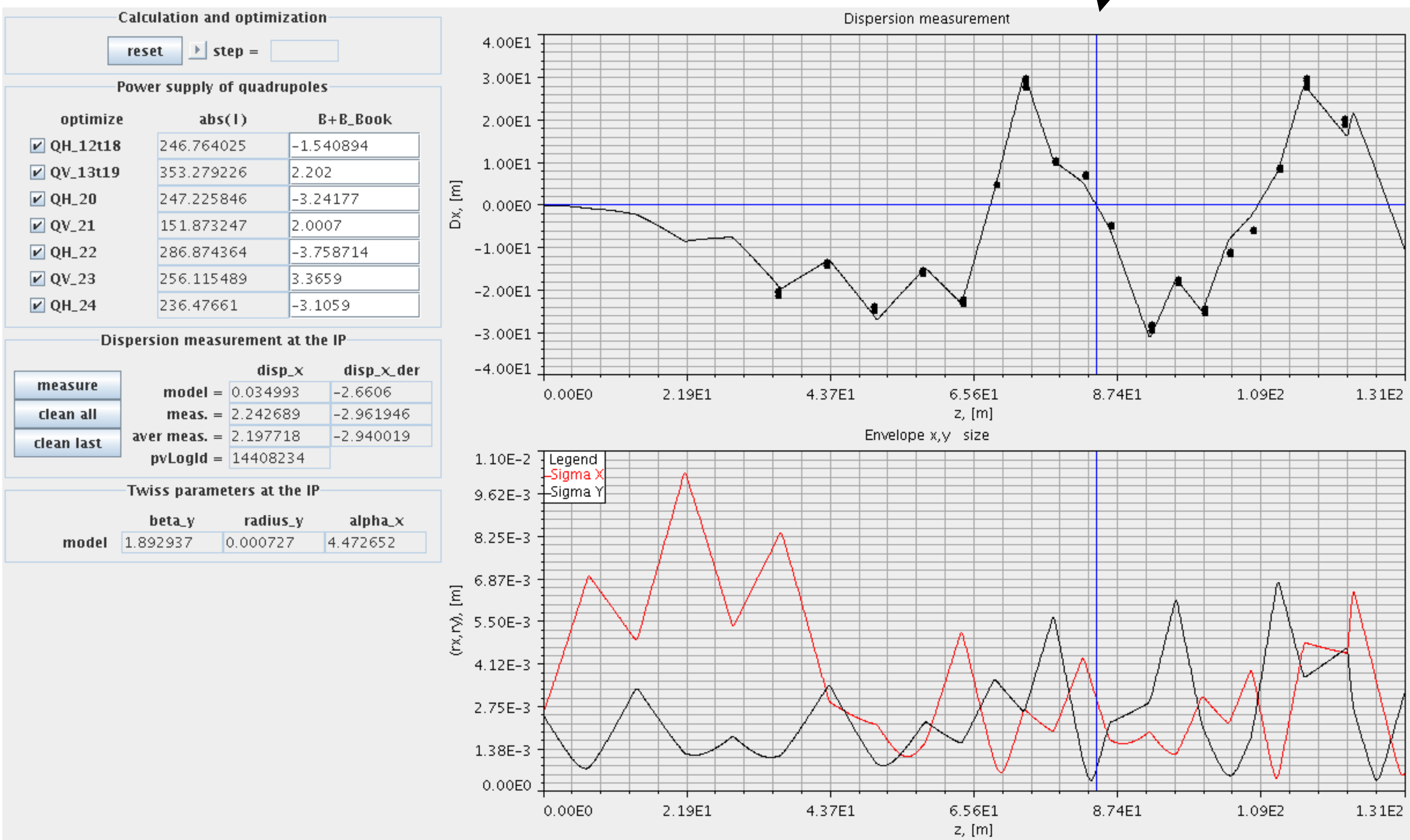
Experimental studies

Parameter	Value	
The longitudinal energy of the ions	1 GeV	
Relative spread of the longitudinal energy σ_T/T	$0.5 \cdot 10^{-3}$	
τ_{FWHM} micro-bunch duration	**30 ps**	
β_x	**< 30 m**	
β_y	**0.75 m**	
α_x	**0**	
α_y	**0**	
D_x' dispersion derivative	**2.6**	
D_x dispersion	**0 m**	
ε_x	$0.3\ \pi \cdot$mm$\cdot$mrad	
ε_y	$0.3\ \pi \cdot$mm$\cdot$mrad	



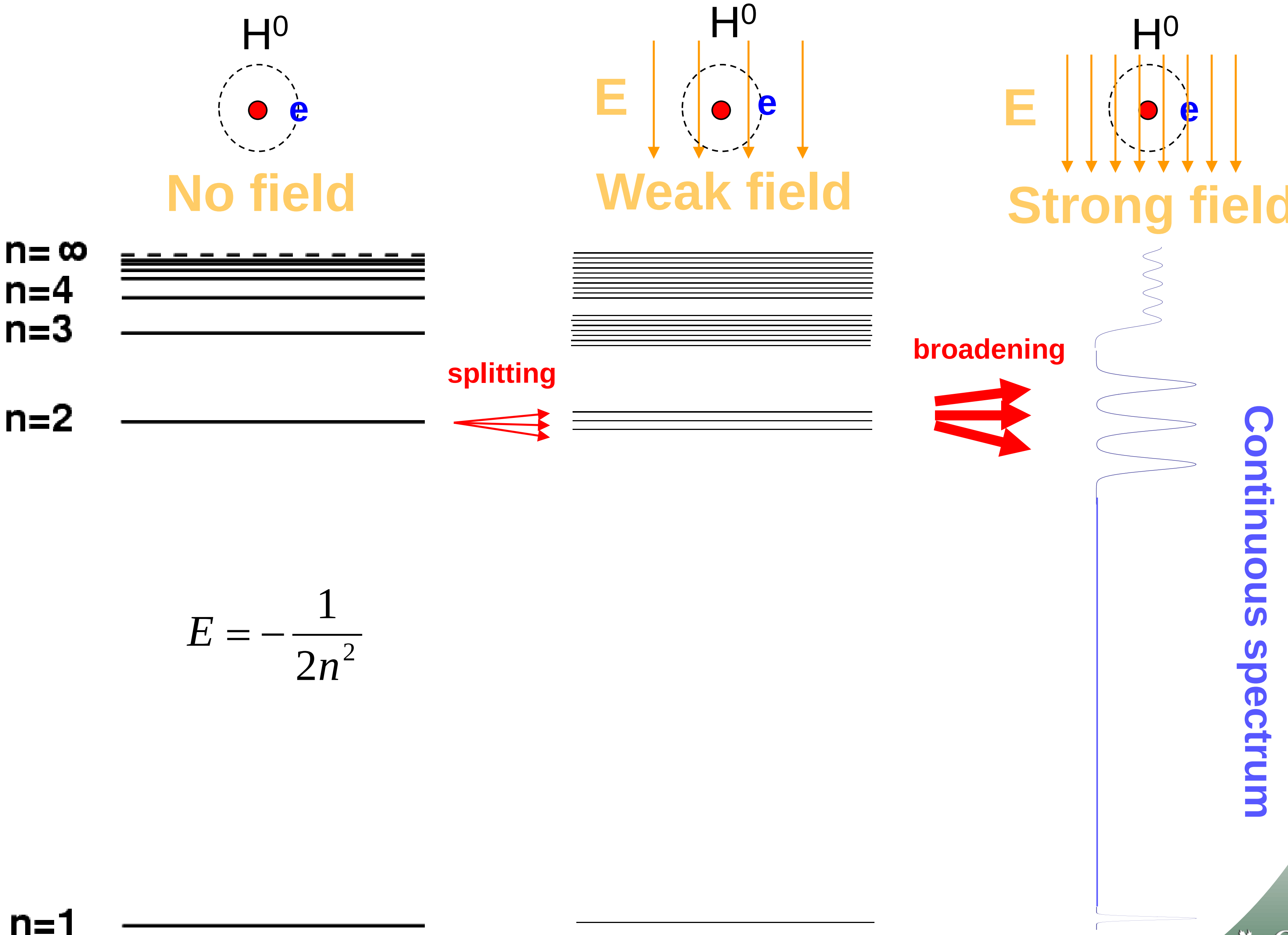
Preliminary tune of dispersion function

Laser Stripping
interaction point



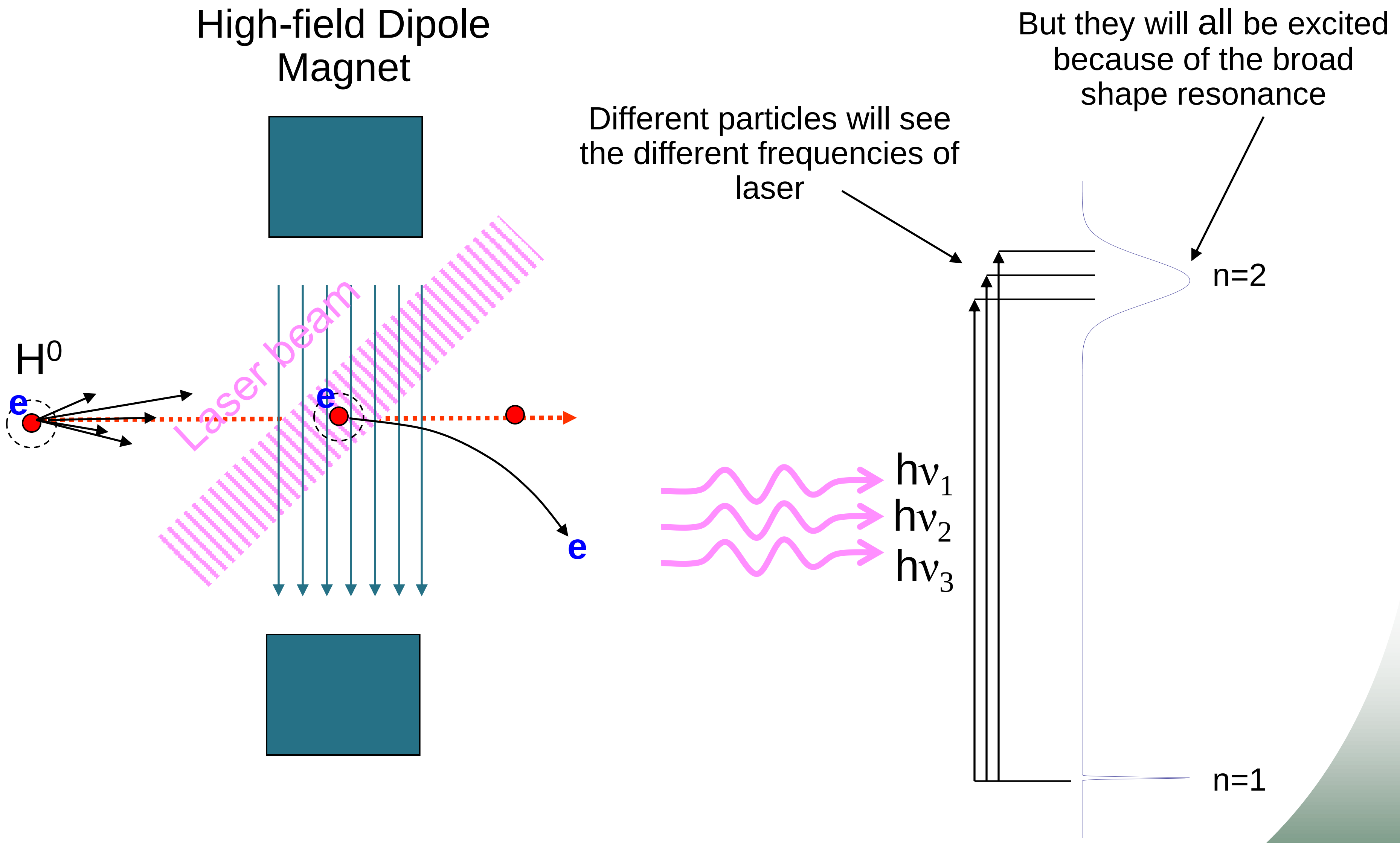
Laser stripping via a broad shape resonance

Hydrogen atom in a strong electric field

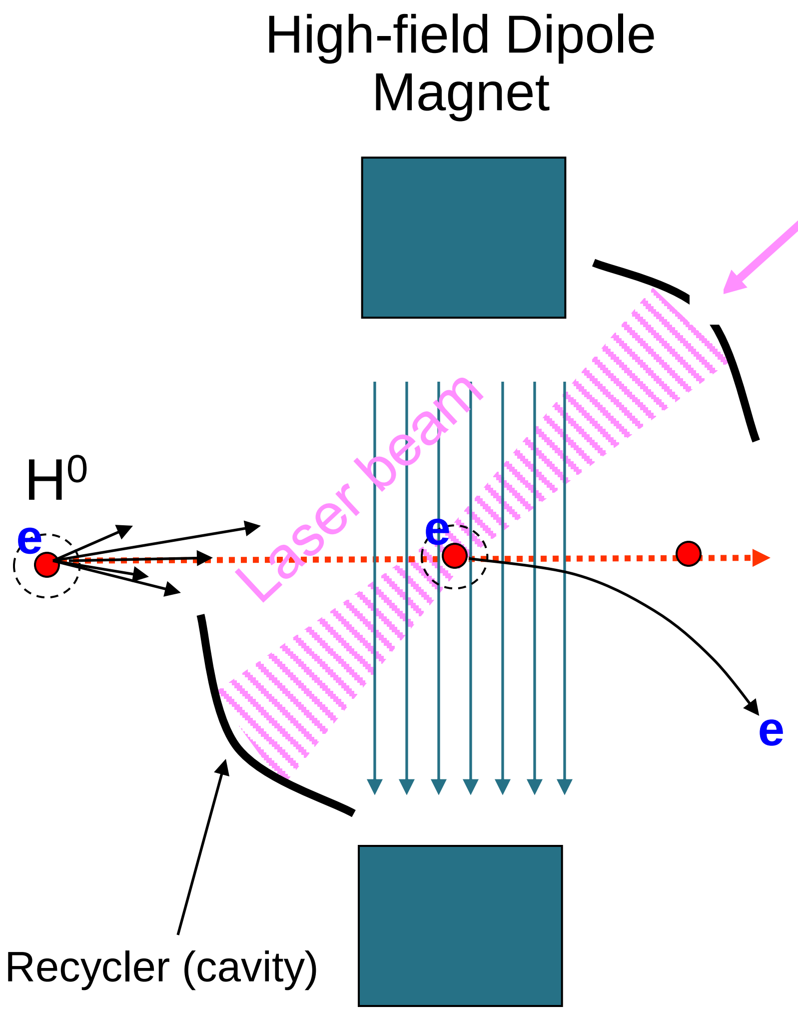


$$E = -\frac{1}{2n^2}$$

Third way to compensate energy spread



Advantages of the scheme



- **Possibility to recycle laser beam**
- **No spontaneous transition losses**
- **Small emittance growth**
- **Using just one stripping dipole magnet (the scheme is more compact)**
- **Can be applied for energy 4 GeV and more (considered as disadvantage)**

Selected references for more details

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