

Efficient Laser ion acceleration from foils and isolated targets

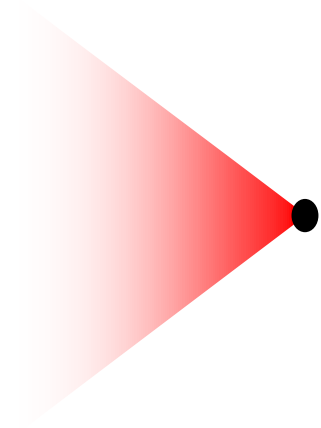
P. Hinz, I. Salahedin, MY. Shi, J. Gebhard, A. Sävert, J. Schreiber, M. Zepf

Helmholtz Institute Jena, Jena, Germany

LPAW 2023, 08.03.2023

Three Experiments

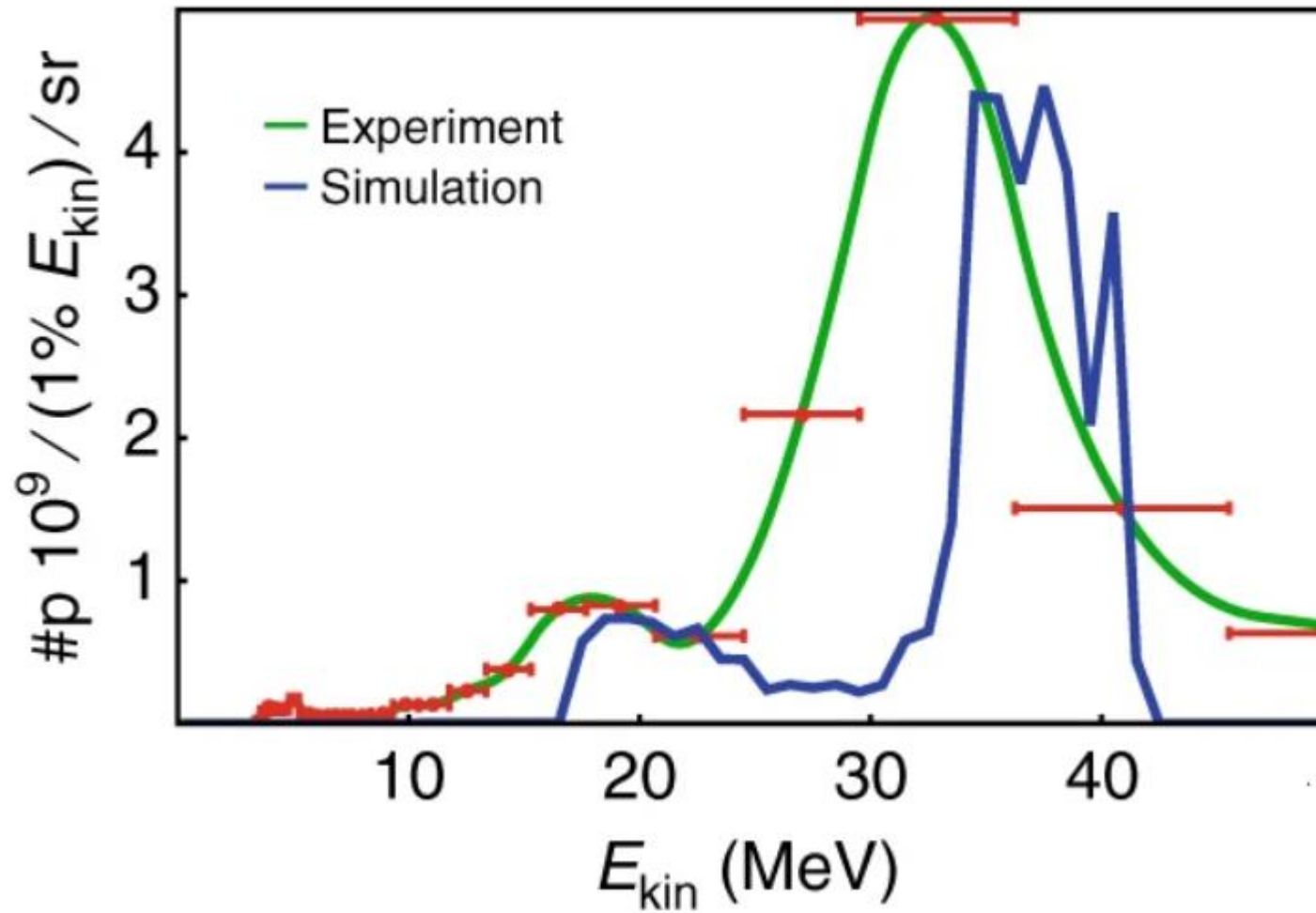
Three Experiments

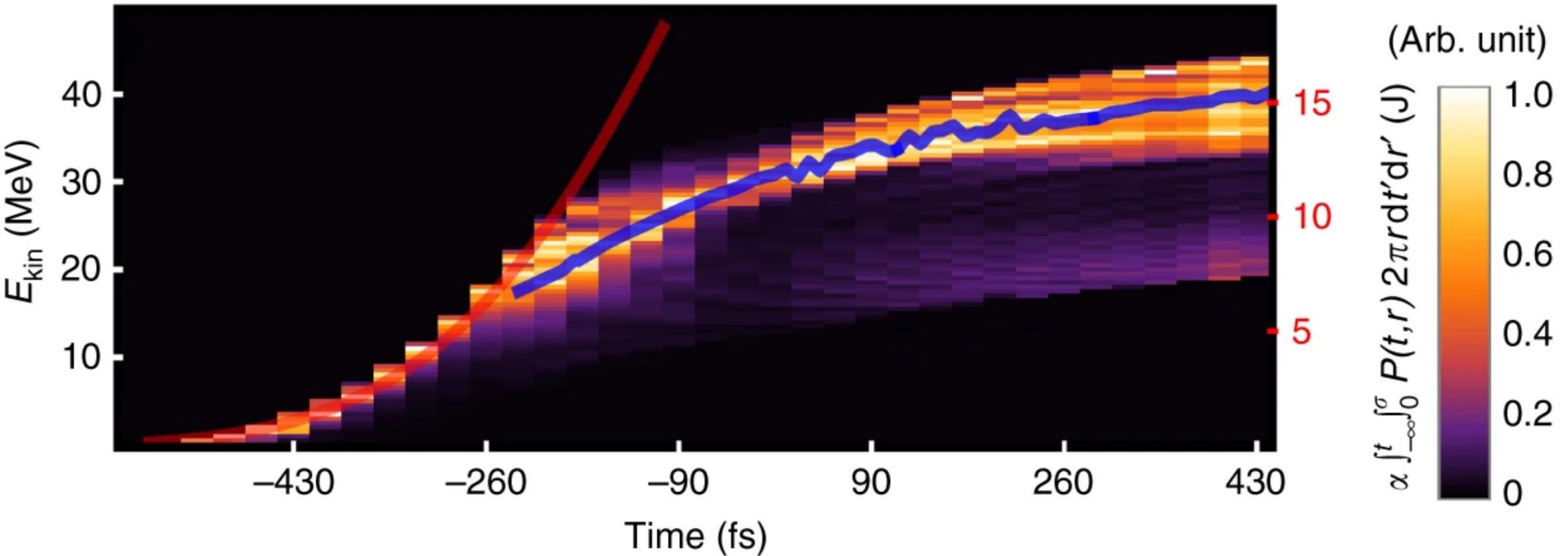


Energy on target ≈ 150 J

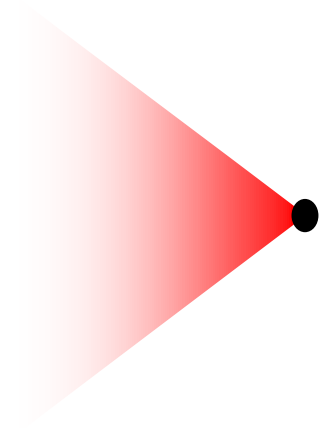
Max Prot. Energy ≈ 45 MeV

Pulsduration ≈ 500 fs





Three Experiments

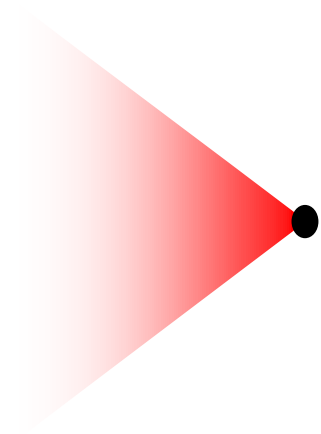


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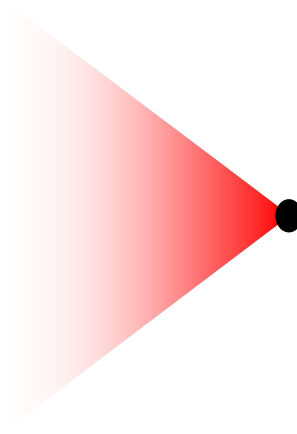
Three Experiments



Energy on target ≈ 150 J

Max Prot. Energy ≈ 45 MeV

Pulsduration ≈ 500 fs

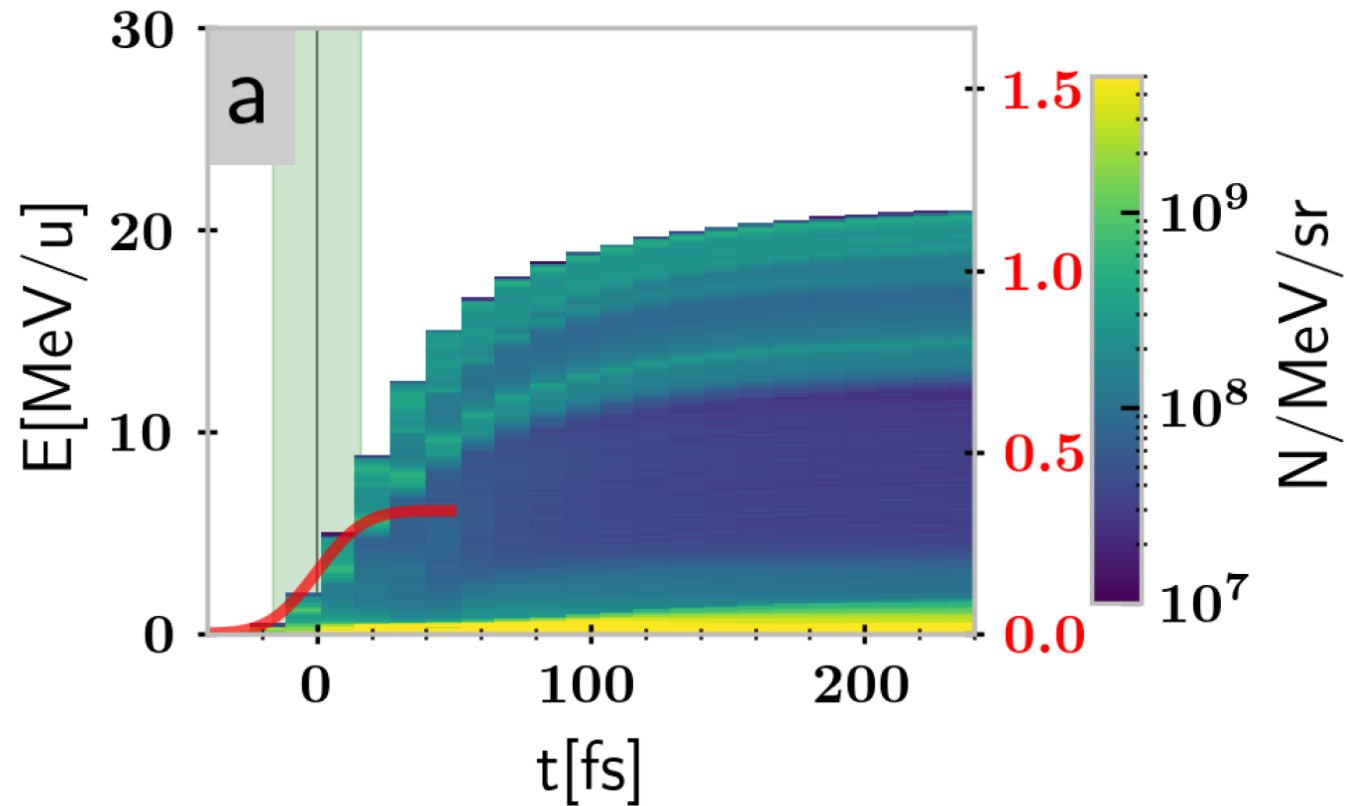


Energy on target ≈ 0.4 J

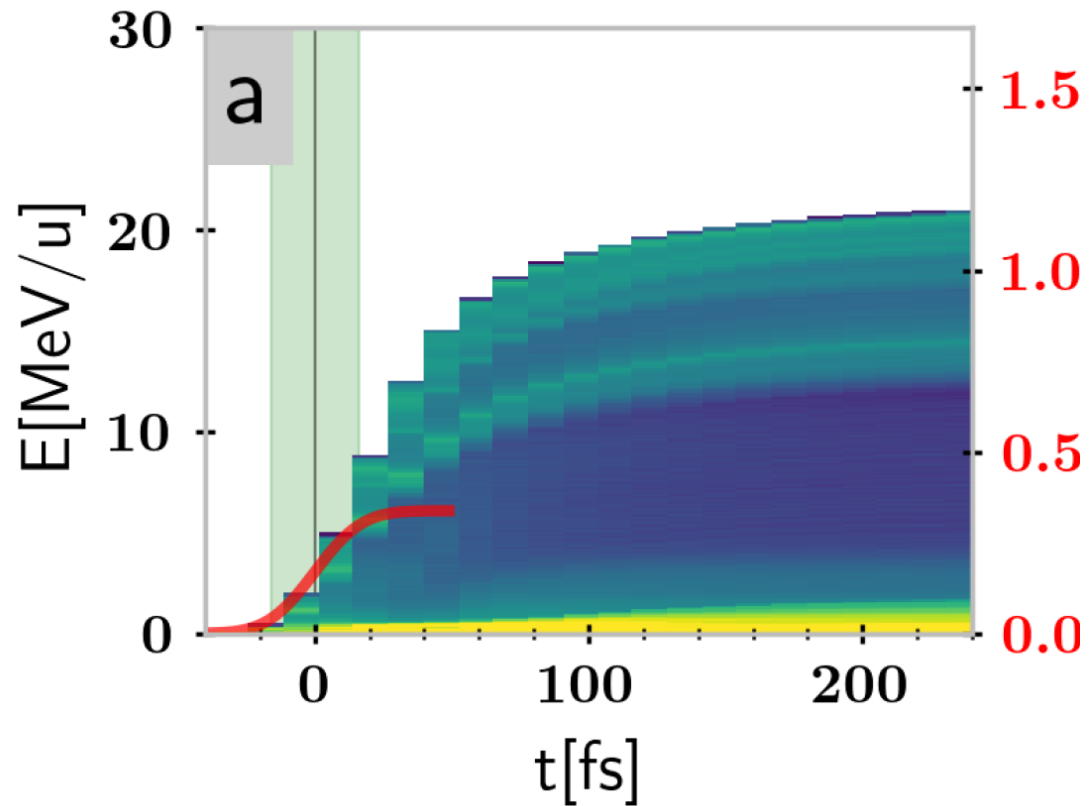
Max Prot. Energy ≈ 27 MeV

Pulsduration ≈ 25 fs

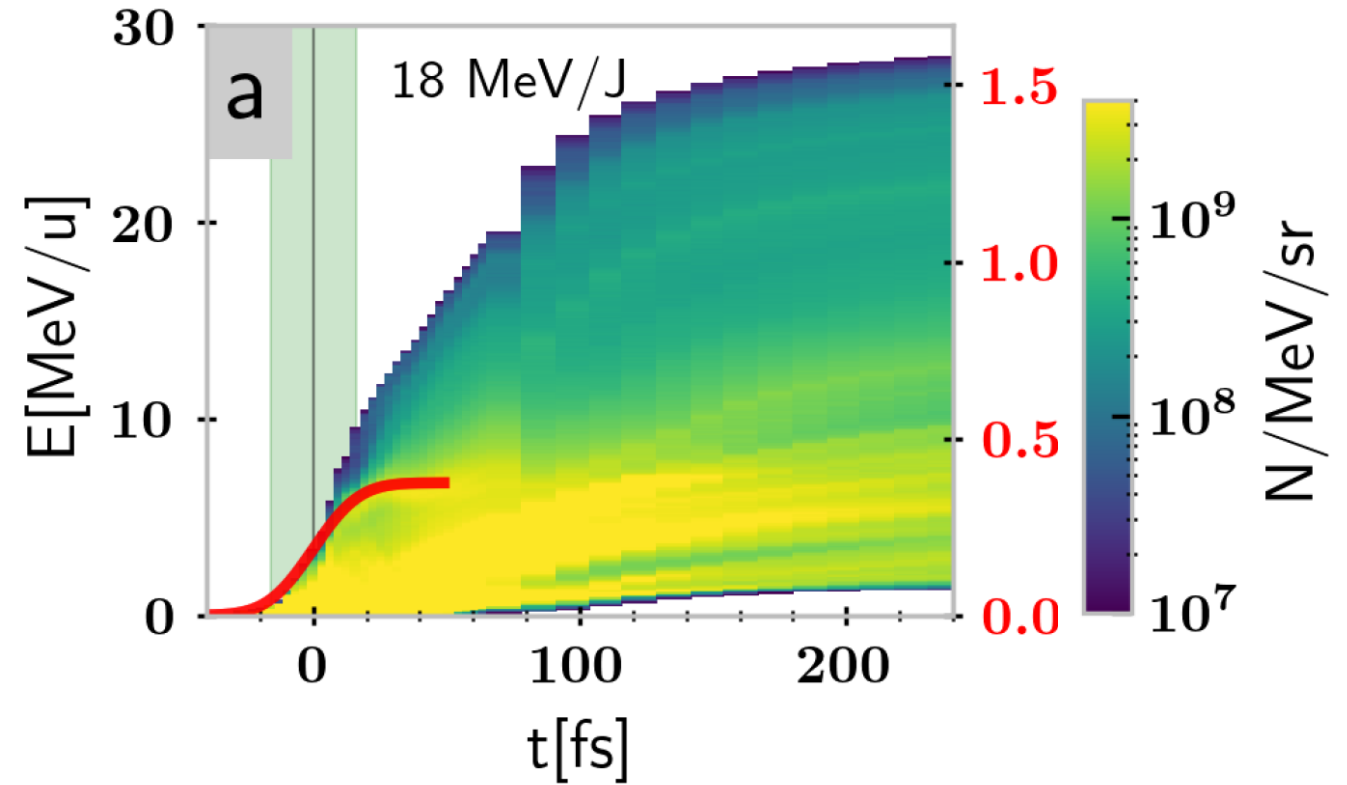
Solid density sphere



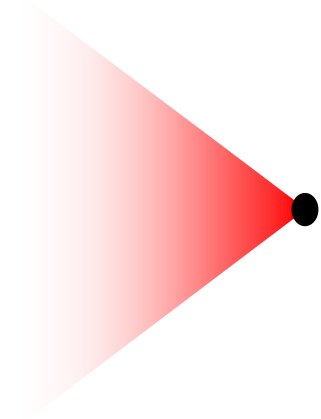
Solid density sphere



Pre-expanded sphere



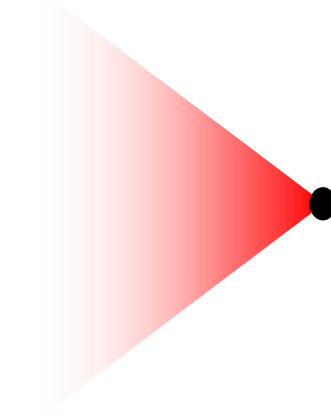
Three Experiments



Energy on target ≈ 150 J

Max Prot. Energy ≈ 45 MeV

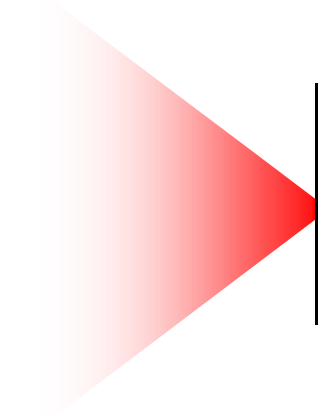
Pulsduration ≈ 500 fs



Energy on target ≈ 0.4 J

Max Prot. Energy ≈ 27 MeV

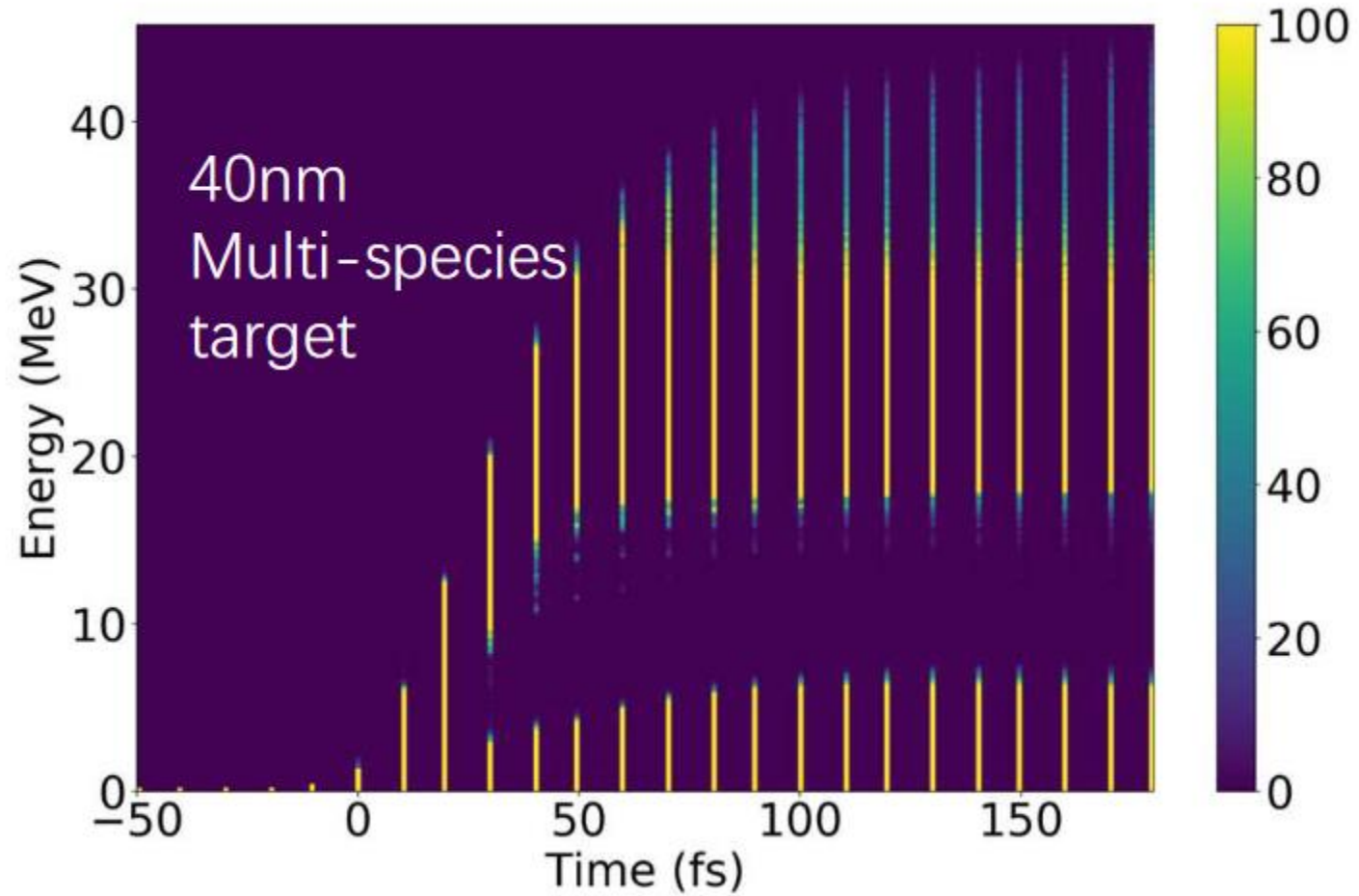
Pulsduration ≈ 25 fs



Energy on target ≈ 2 J

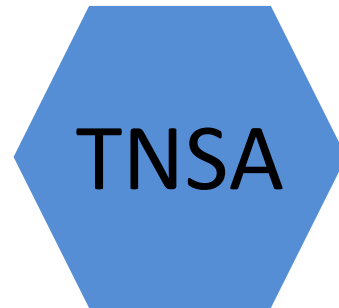
Max Prot. Energy ≈ 35 MeV

Pulsduration ≈ 25 fs

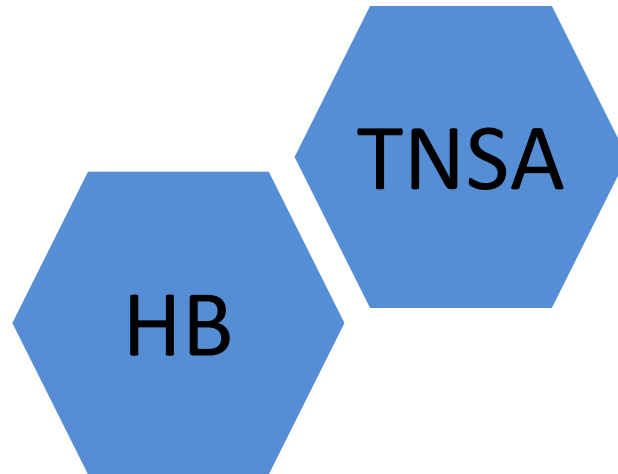


Many different acceleration mechanisms exist

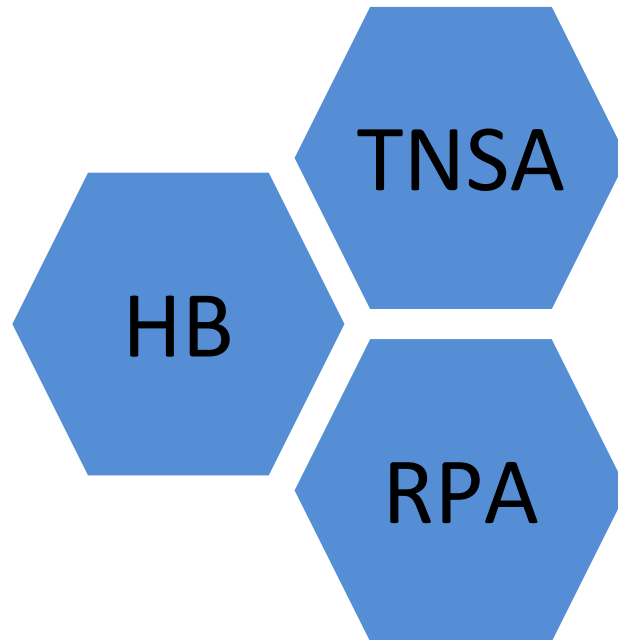
Many different acceleration mechanisms exist



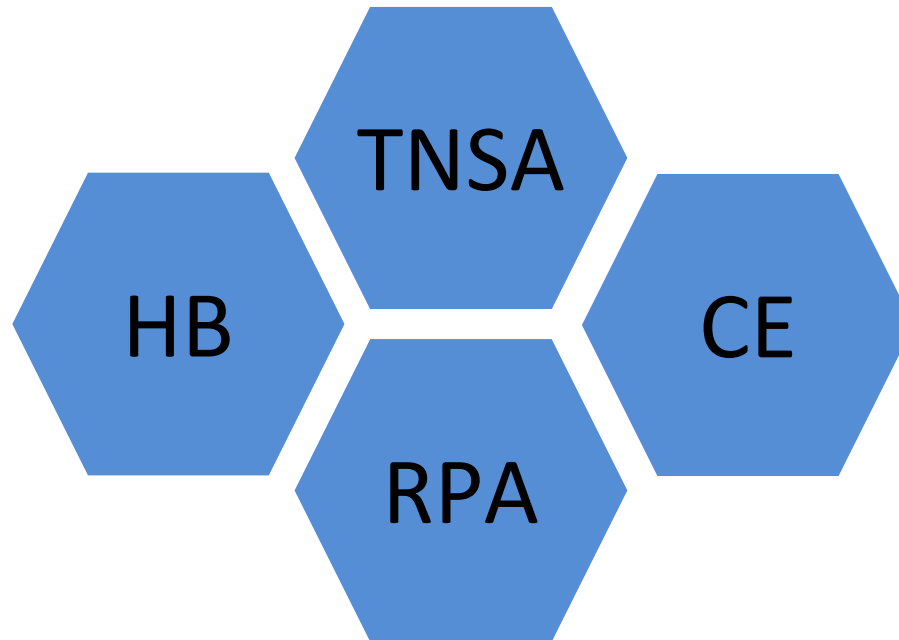
Many different acceleration mechanisms exist



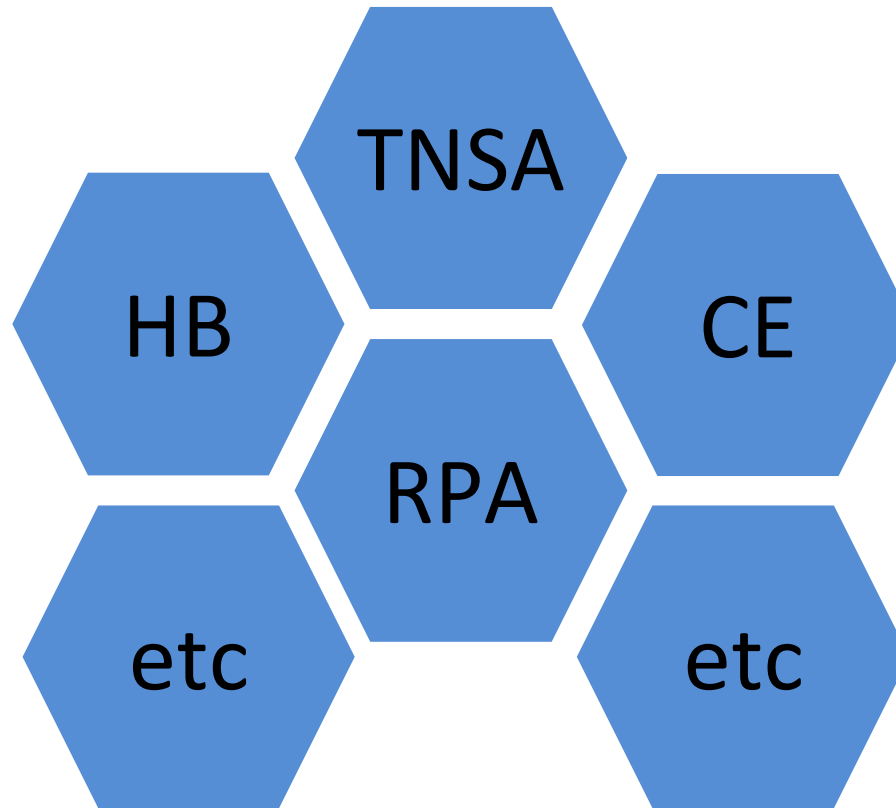
Many different acceleration mechanisms exist



Many different acceleration mechanisms exist



Many different acceleration mechanisms exist



HB

RPA

etc

TNSA

CE

etc

HB

RPA

etc

Forces

TNSA

CE

etc

Potential

Coulomb explosion

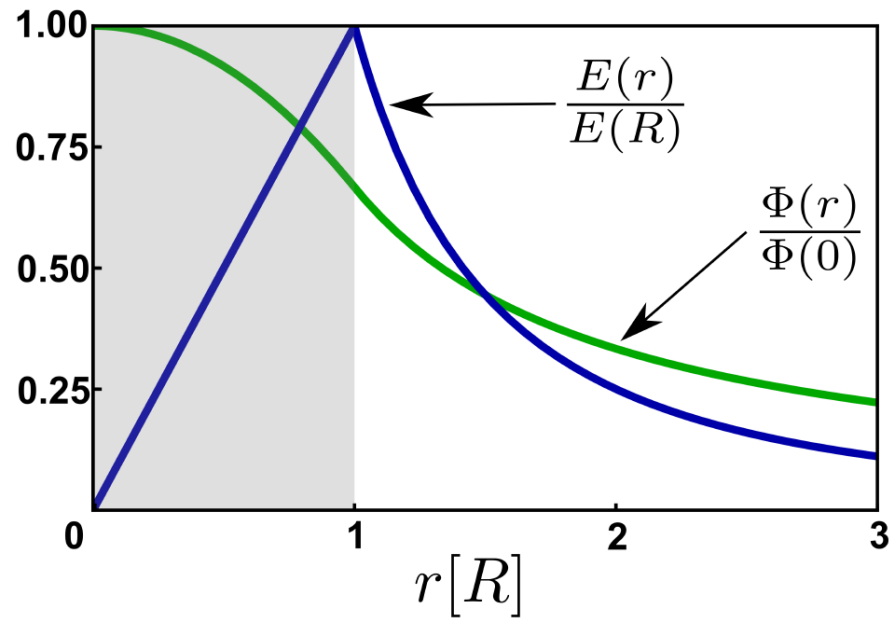


CE

Coulomb explosion

$$\Phi(r) = \begin{cases} \frac{1}{8\pi\epsilon_0} \frac{Q}{R} \left(3 - \frac{r^2}{R^2}\right) + C_1 & r \leq R \\ \frac{1}{4\pi\epsilon_0} \frac{Q}{r} + C_1 & r > R \end{cases}$$

$$E(r) = -\nabla U(r) = \frac{1}{4\pi\epsilon_0} \frac{Q_{enc}}{r^2} = \begin{cases} \frac{1}{4\pi\epsilon_0} \frac{Q}{R^3} r & r \leq R \\ \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} & r > R \end{cases}$$

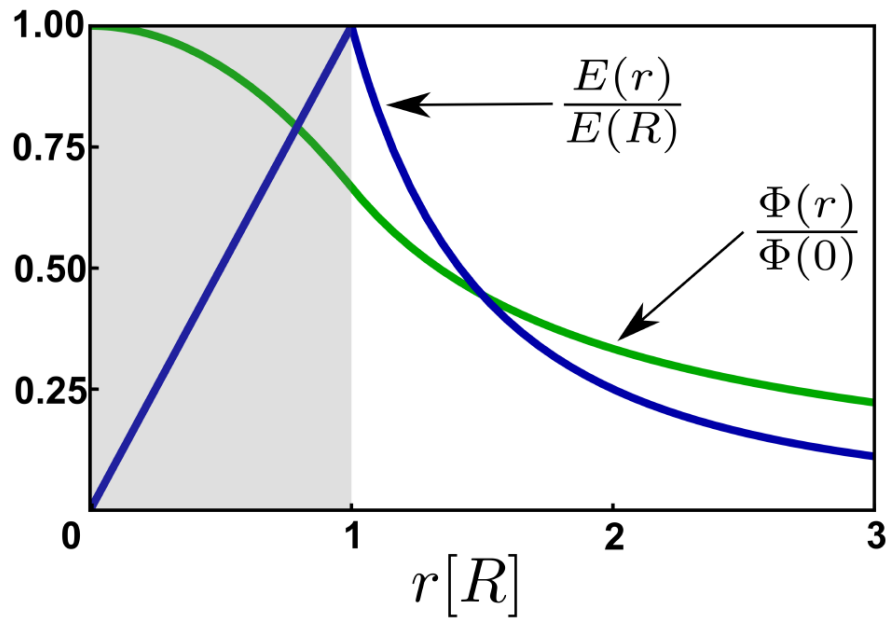


Coulomb explosion

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$$\mathcal{E}_{kin,max} = q^2 \frac{n_{q0} R^2}{3\epsilon_0}$$

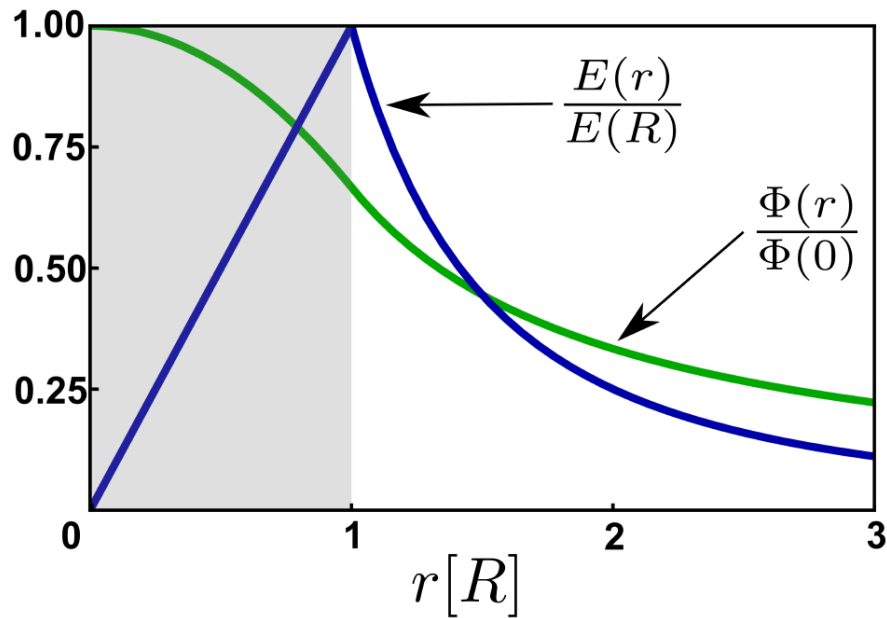


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$$\mathcal{E}_{Coulomb} = \frac{\epsilon_0}{2} \int E(r)^2 dV = \frac{4\pi q^2 n_{q0}^2 R^5}{\epsilon_0 15}$$



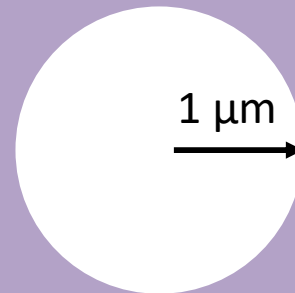
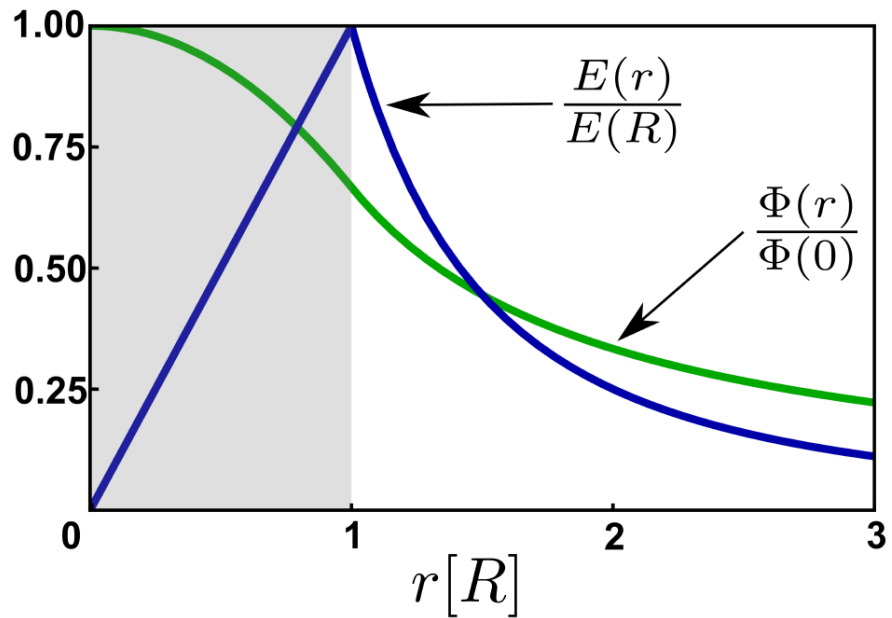
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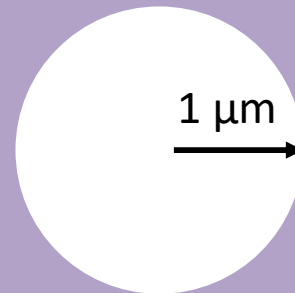
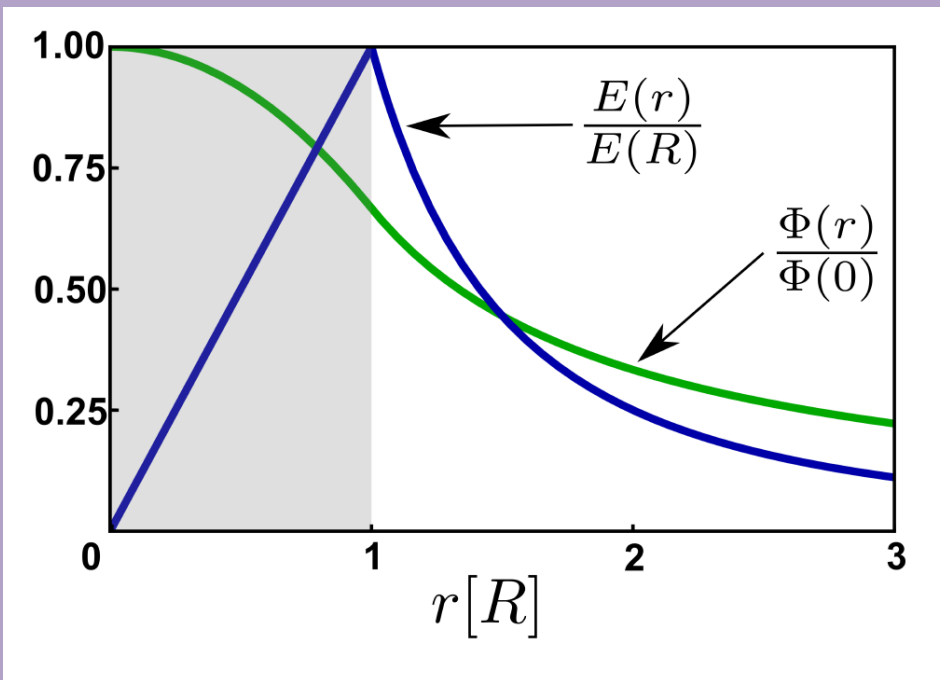
Coulomb explosion

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0.5 GeV

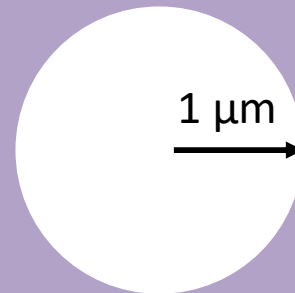
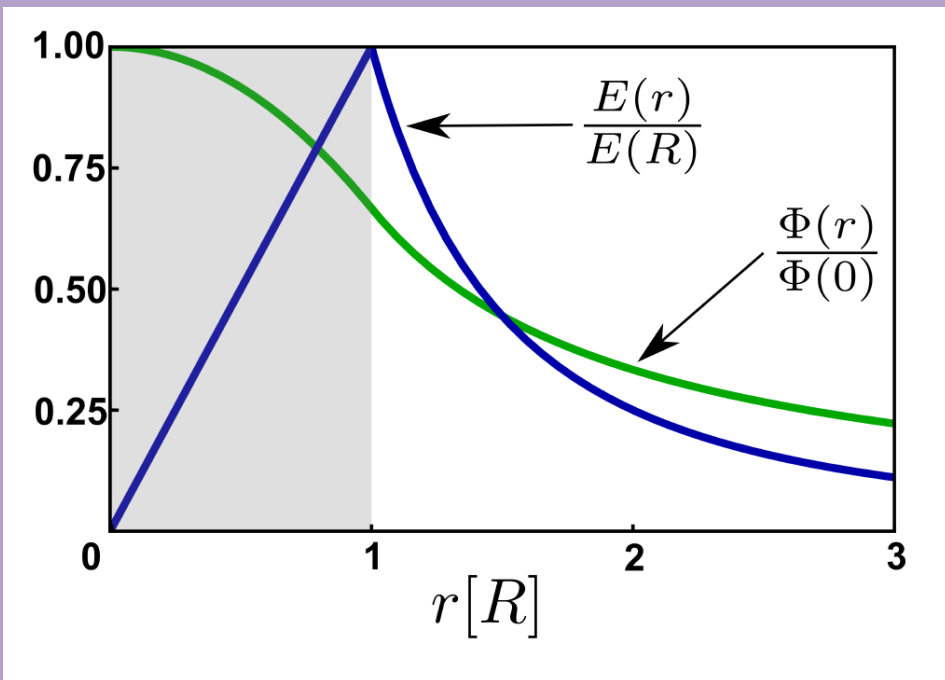
Coulomb explosion

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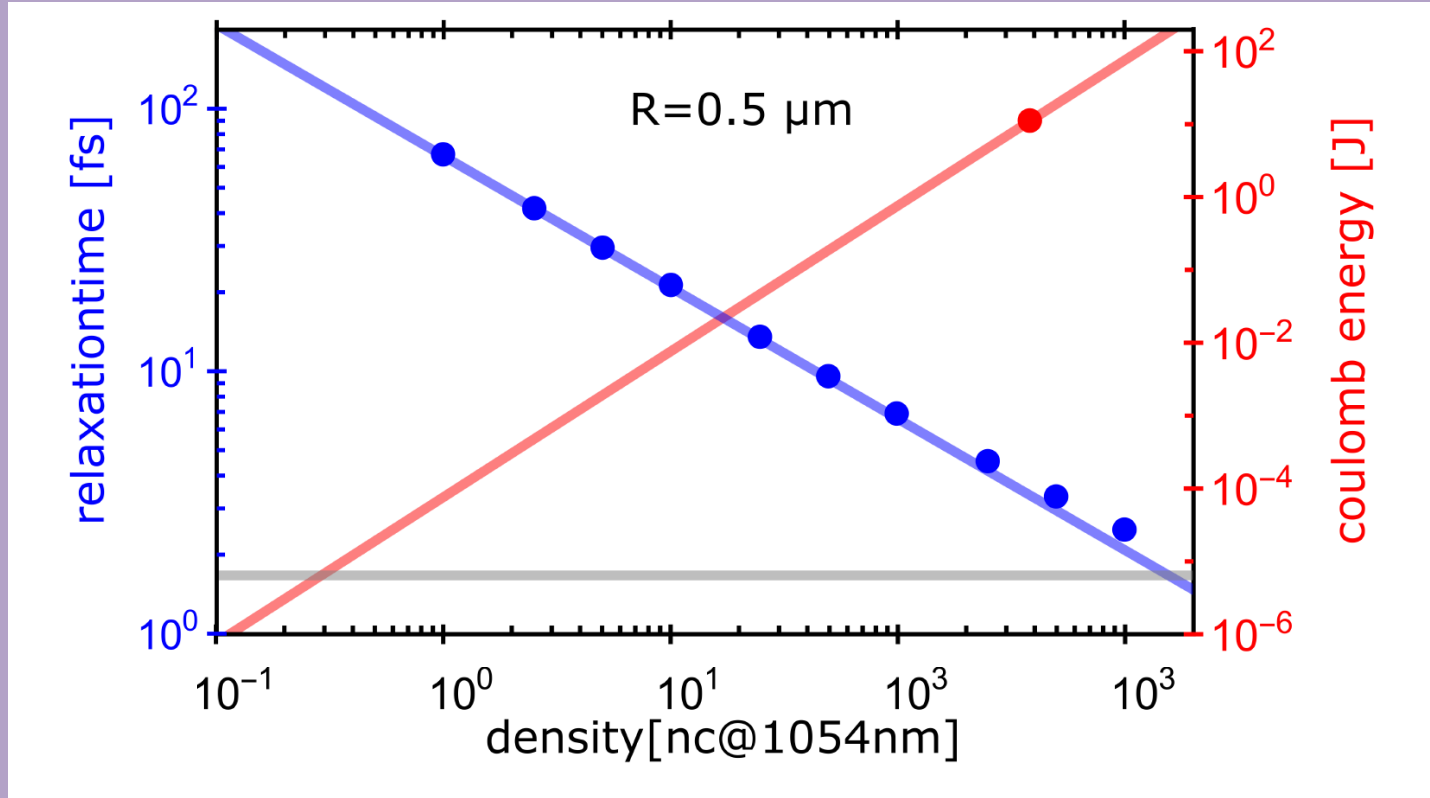


0.5 GeV

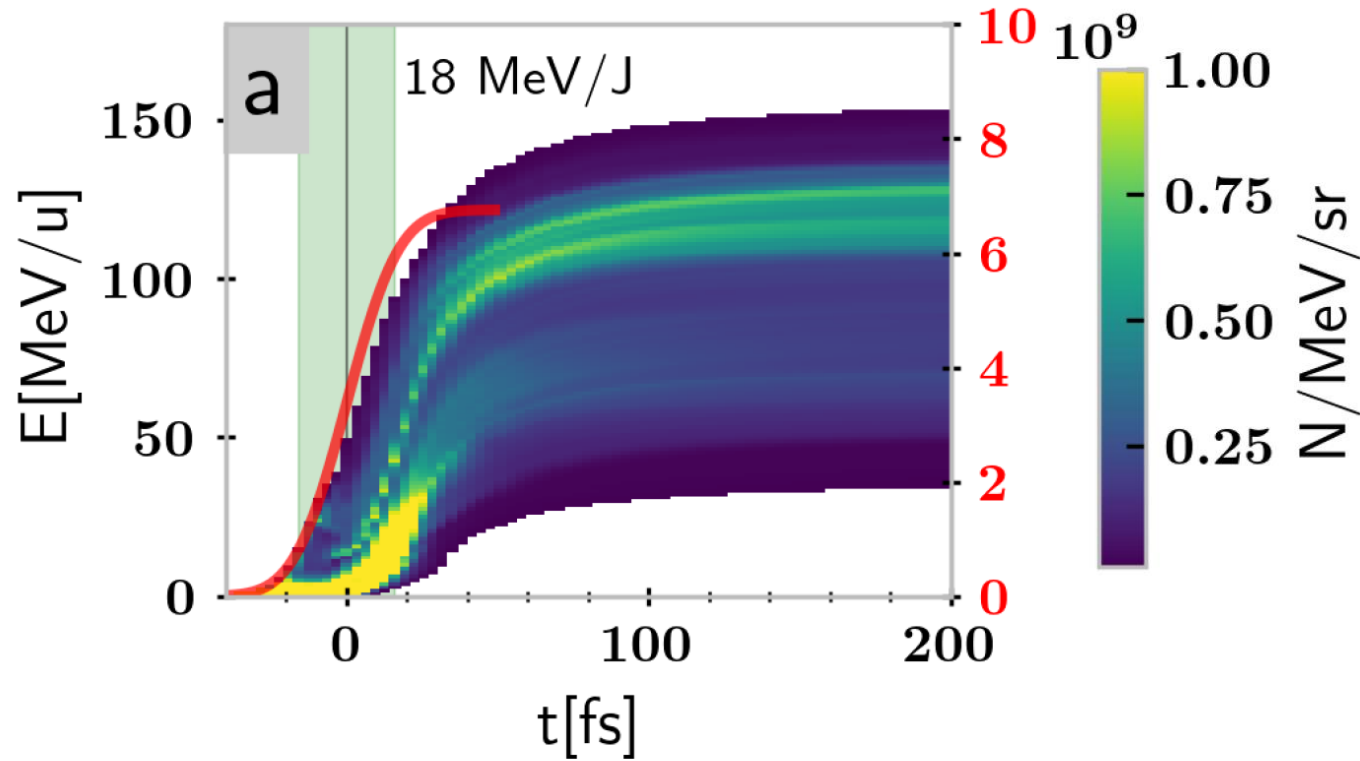
8.9 J

$$t_{\frac{1}{2}} = \sqrt{\frac{3\epsilon_0 m_q}{2n_{q0} q^2}} \left(\sqrt{2} + \operatorname{arsinh}(1) \right) \approx \frac{2.81}{\omega_{pi}}$$

Coulomb explosion



Pre-expanded sphere with more laser energy



- Acceleration after the laser pulse due to stored energy
- Highly efficient acceleration possible with different target systems
- Timescale for intra pulse expansion motivated (work in progress)

Coulomb explosion

$$t_{\frac{1}{2}} = \sqrt{\frac{3\epsilon_0 m_q}{2n_q q^2}} \left(\sqrt{2} + \operatorname{arsinh}(1) \right) \approx \frac{2.81}{\omega_{pi}}$$

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Coulomb explosion

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$$I = \frac{C_{Abs} \mathcal{E}_{Coulomb}}{t_{\frac{1}{2}} \pi R^2} = \frac{1}{2} c \epsilon_0 a_0^2 E_{rel}^2$$

Coulomb explosion

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$$a_0 = \pi \frac{n_e}{n_c} \frac{R}{\lambda} \sqrt{\frac{32 C_{Abs} R}{15 t_{\frac{1}{2}} c}}$$