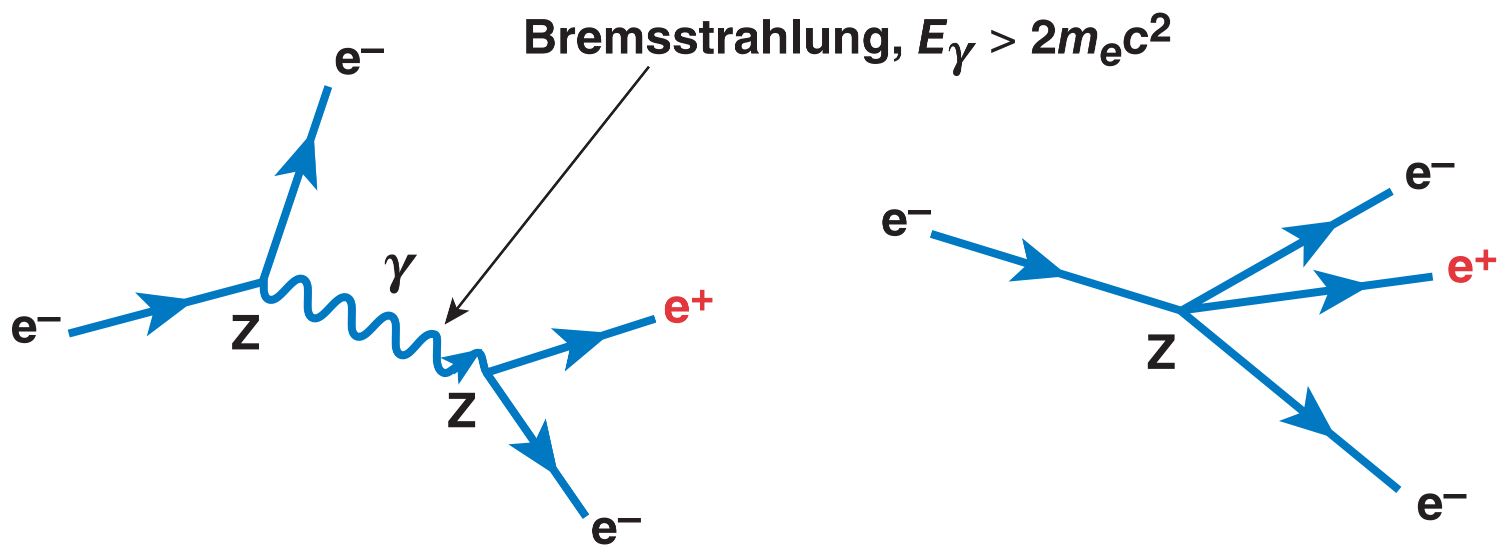
Design of a Pair-Plasma Production Experiment for OMEGA EP



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Summary

OMEGA EP can potentially produce an electron–positron-pair plasma containing between 10^{11} and 10^{12} positrons

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- The calculations assume a total laser energy of 5 kJ and a 40% conversion efficiency of laser energy into hot electrons.
- For the generation of pairs, total available energy is more important than obtaining higher laser intensities (assuming a laser intensity of at least $\sim10^{19}$ W/cm^2).
- If the pairs can be confined to a volume of $\sim10^{-4}$ cm^3, the first-ever pair *plasma* will be produced in the laboratory.
- Flexibility of having two beams could help confine the pairs.

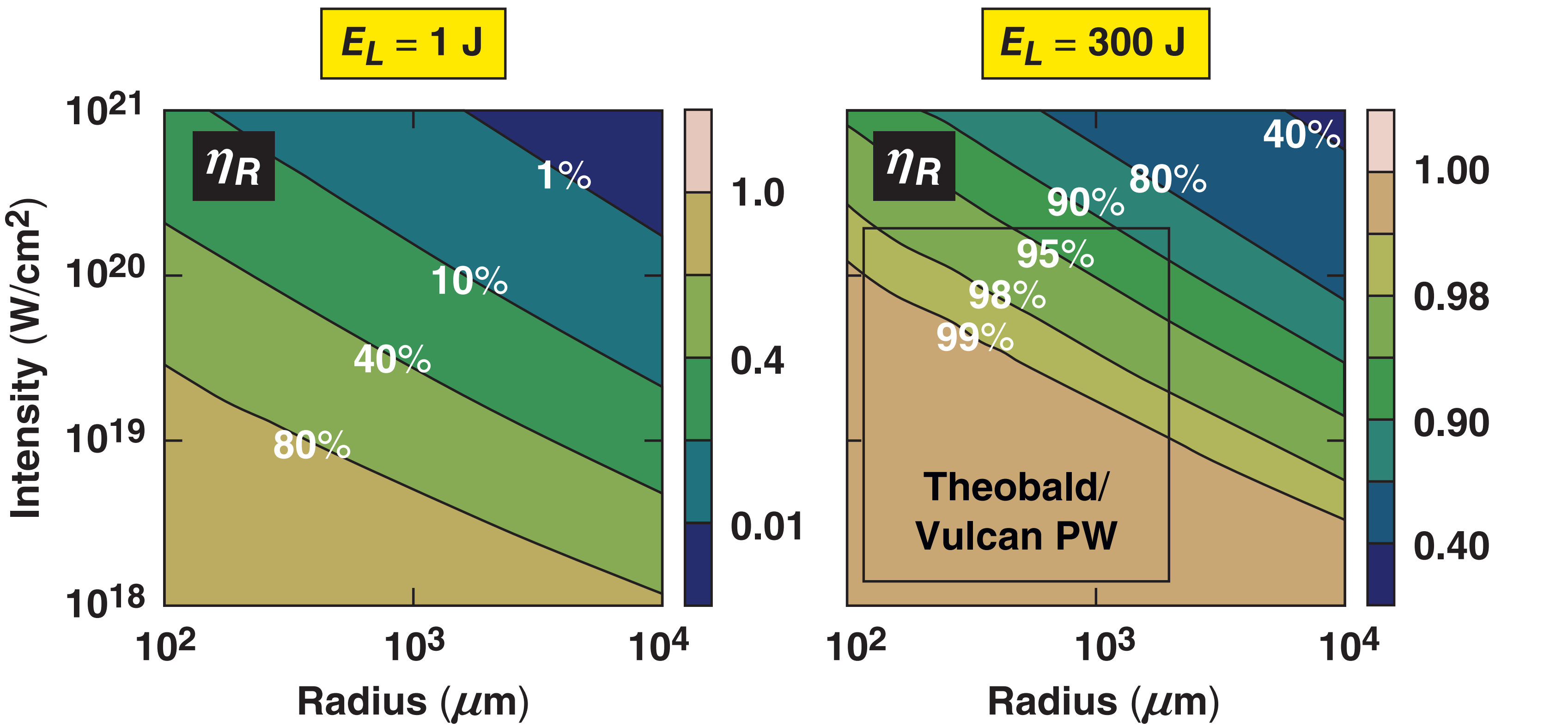
Pair creation due to the Trident process can be estimated since the cross section is well known

- Of the two mechanisms that are important for OMEGA EP parameters, the Trident process is dominant for targets thinner that a few hundred microns.
  - "Trident" process: $e^- + Z \rightarrow e^- + Z + e^+ + e^-$

- Probability of positron production (per electron) is calculated to be between $W_+ \backsimeq (10^{-4}$ to $10^{-3})$ [Gryaznykh *et al*. JETP Lett. (1998)].
  - assuming MeV electron temperatures
  - all electrons stop in the target
    - refluxing of hot electrons from sheath fields assures this

For targets less than ~1 mm in size and for laser energies of more than few hundred joules, essentially all of the hot electrons reflux

- A large target is not required for high yield.



TC7343a

For small targets, the Bethe–Heitler process is less important than Trident

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- For Au targets ($Z = 79$) greater than ~100 μm thick, this process becomes competitive with Trident:

$$e^- + Z \rightarrow e^- + Z + \gamma,\ \gamma + Z \rightarrow Z + e^- + e^+$$

  – The bremsstrahlung efficiency is well known ($E_\gamma > 1.02$ MeV):

$$(dE/dx)_{rad}/(dE/dx)_{coll} \sim 10\%$$

  – Pair production is the dominant attenuation mechanism for gamma photons at these energies.

  – Most of this radiation escapes the target unless it is thick.

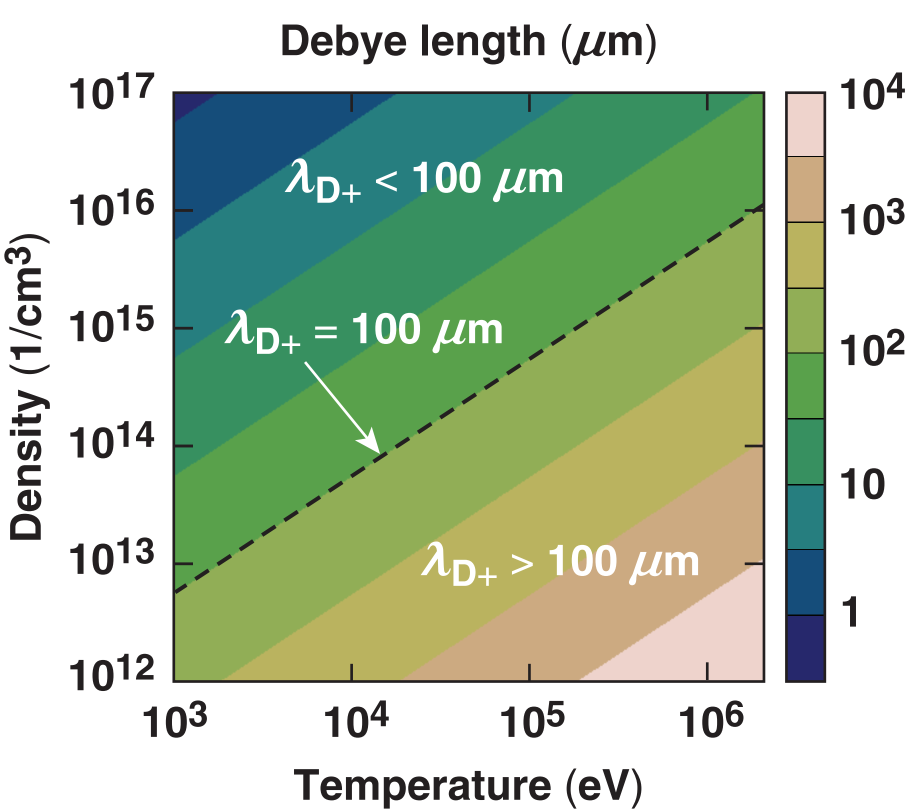
  – For 1 MeV, γ rays in Au $\mu\rho = (0.1)\ (19.3) = 1.93\ \text{cm}^{-1}$.

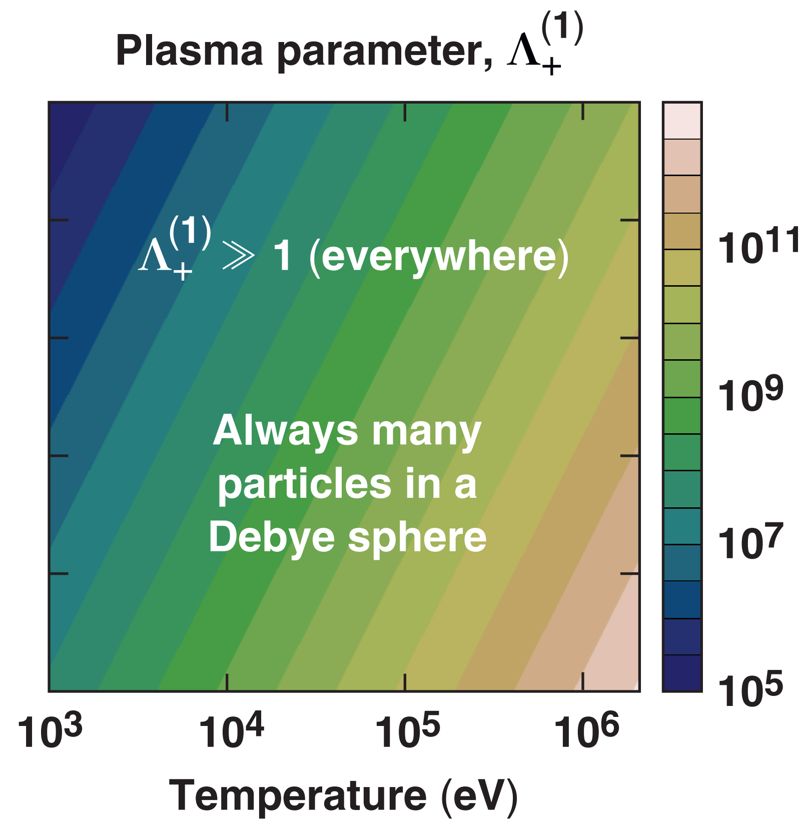
  – $\Delta I/I_0 = 1 - \exp[-x(\text{mm})/7.2] \sim 1\%$ at $x = 100\ \mu$m

TC7222a

For the positrons to be considered a plasma, two conditions need to be met

- Many particles in a Debye sphere: $\Lambda_{+}^{(1)} \equiv n_{+}\lambda_{D+}^{3} \gg 1$
- System must be larger than the Debye length: $\Lambda_{+}^{(2)} = \ell_{system}/\lambda_{D+} \gg 1$





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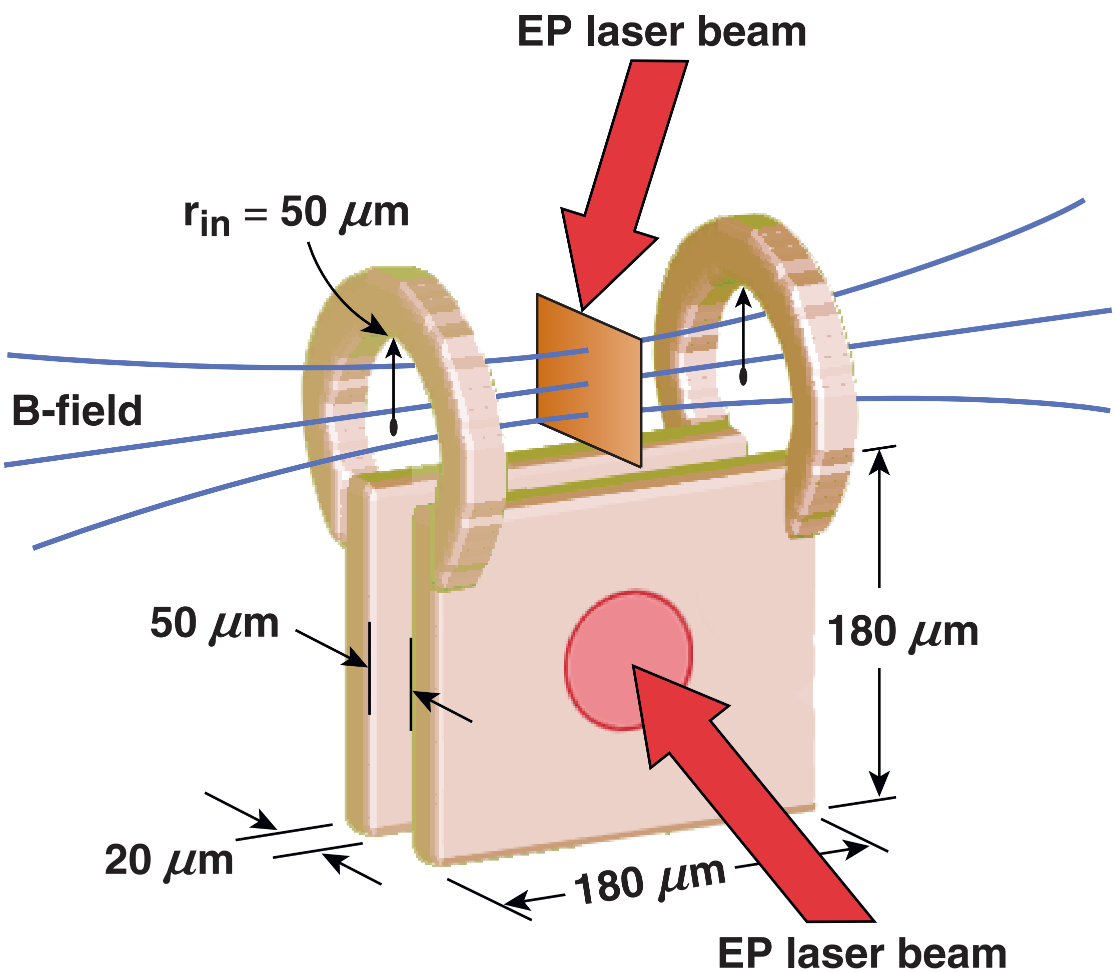
Positron expansion makes it difficult to obtain the required density of $\gtrsim 10^{16}$ cm^{-3}

- Unlike hot electrons, positrons do not reflux.
- Spherical expansion must be limited to a radius of 300 μm,
  - free expansion at *c* for 1 ps
  - Debye length is similar to system size
  - $\Lambda_{+}^{(2)} = 2.4\left(N_{+}/10^{11}\right)^{1/2}\left(1\ \text{MeV}/T_{+}\right)^{1/2}\left(1\ \text{ps}/\tau_{p}\right)^{1/2}$
- Limit expansion to one dimension only.
  - system size ~100 Debye lengths
  - $\Lambda_{+}^{(2)} = 86\left(N_{+}/10^{11}\right)^{1/2}\left(1\ \text{MeV}/T_{+}\right)^{1/2}\left(\tau/1\ \text{ps}\right)^{1/2}\left(100\ \mu\text{m}/r_{\text{conf}}\right)$
  - magnetic field, ponderomotive force*

TC7345a

*E. P. Liang *et al*., Phys. Rev. Lett. 81, 4887 (1998).

The flexibility of multiple EP beams can be utilized to magnetize a foil target

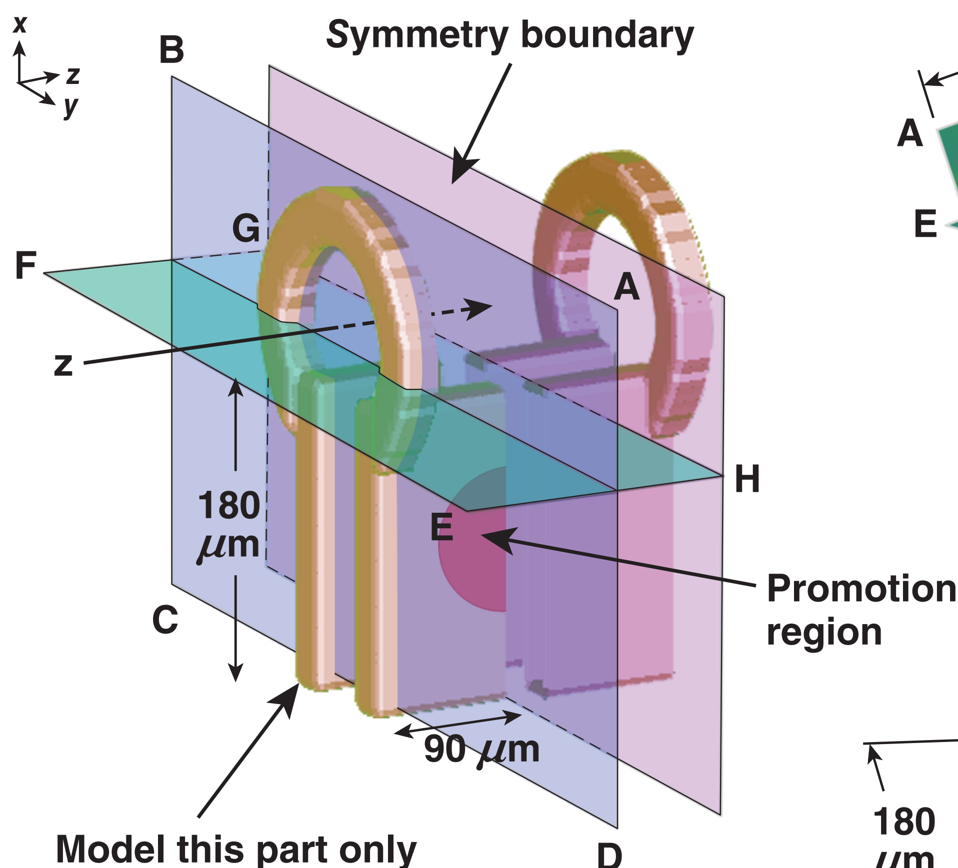


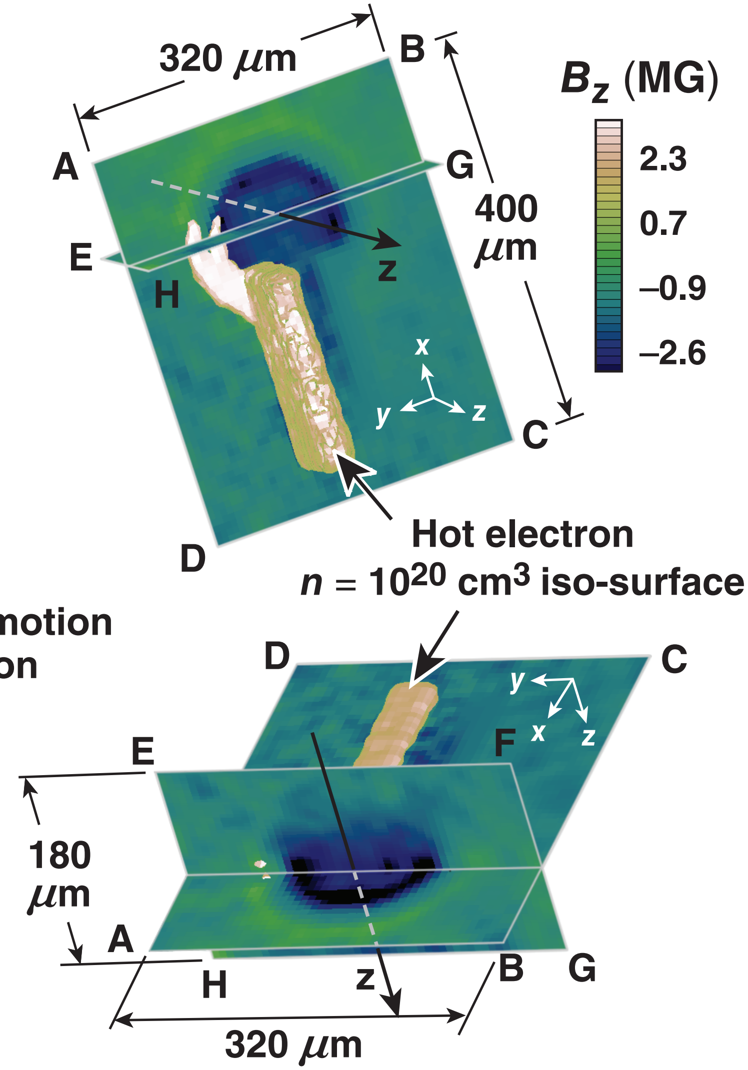
- One EP beam interacts with suitable target.
- Other beam creates positrons in second target, which is immersed in the B-field created by the first beam.
- Expansion of positrons is influenced.
- Similar targets have been fielded.*

*H. Daido *et al*., Phys. Rev. Lett. 56, 846 (1986); N. C. Woolsey *et al*., Phys. Plasmas 8, 2439 (2001).

TC7346

The first part of the scheme has been investigated with *LSP* indicating that MG magnetic field strengths can be obtained



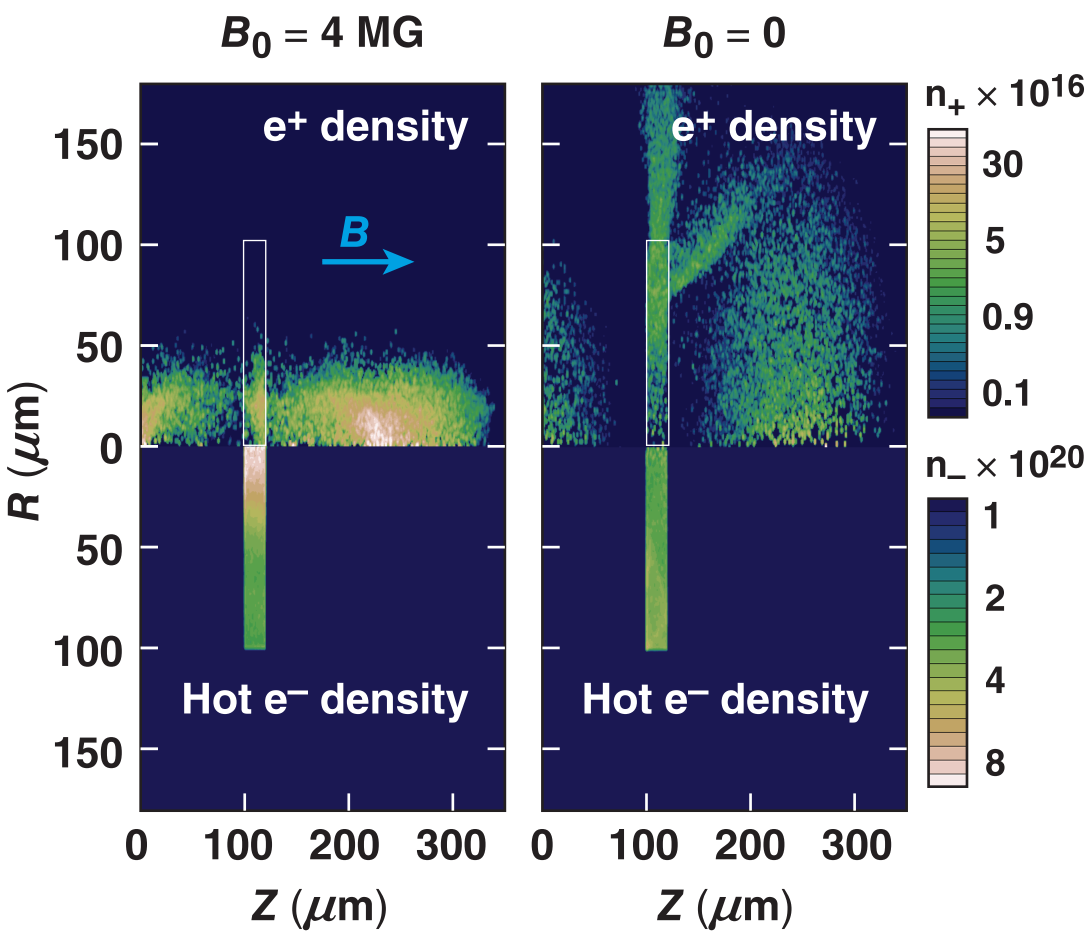


TC7347

One-MG magnetic fields are attainable and would be sufficient to confine radial positron expansion to within a few hundred microns

- Positron synchrotron frequency $\omega_{Ce} = eB/\gamma mc$
  - $\omega_{Ce} = 1.76 \times 10^{13} (B/1\text{ MG})(1/\gamma)$ rads s^{-1}
- Gyroradius $r_{Ce} = \beta_{\perp} c/\omega_{Ce}$
  - $r_{Ce} = 17(1\text{ MG}/B)(\gamma)$ μm
- From 1-D expansion on previous slide: $\Lambda_{+}^{(2)} \sim 40$
  - even better if $v << c$

LSP calculations confirm that an external axial magnetic field of 4 MG is sufficient to achieve the required positron density



- An external magnetic field has been imposed in the *LSP* calculations.
- The positrons are emitted in a jet along the direction of the imposed field.
- Interesting dynamics are observed in the absence of an external magnetic field.
- This arises due to a self-generated azimuthal magnetic field.

TC7349

Diagnosing the pair plasma provides some significant challenges

- The presence of positrons can be diagnosed by observing their annihilation radiation (back to back photons at 511 keV)
- Pair plasmas are "symmetric," leading to a difference in the linear-mode structure compared to "asymmetric" e–i plasmas
- Cutoffs for *x* waves differ from e–i plasmas
- No Faraday rotation
- Unfortunately, collective waves have long wavelengths >100 μm
- The probe beam would need to be in the submillimeter range

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