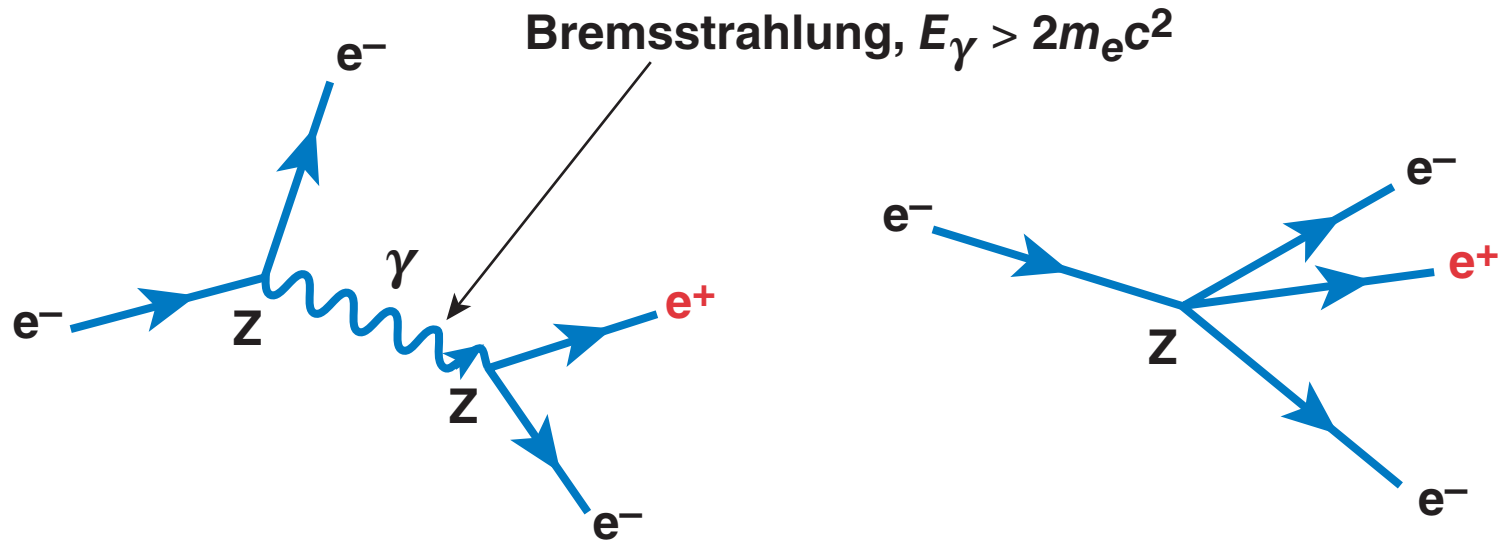


Design of a Pair-Plasma Production Experiment for OMEGA EP



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Summary

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



- 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 $\sim 10^{19}$ W/cm²).
- If the pairs can be confined to a volume of $\sim 10^{-4}$ cm³, the first-ever pair *plasma* will be produced in the laboratory.
- Flexibility of having two beams could help confine the pairs.

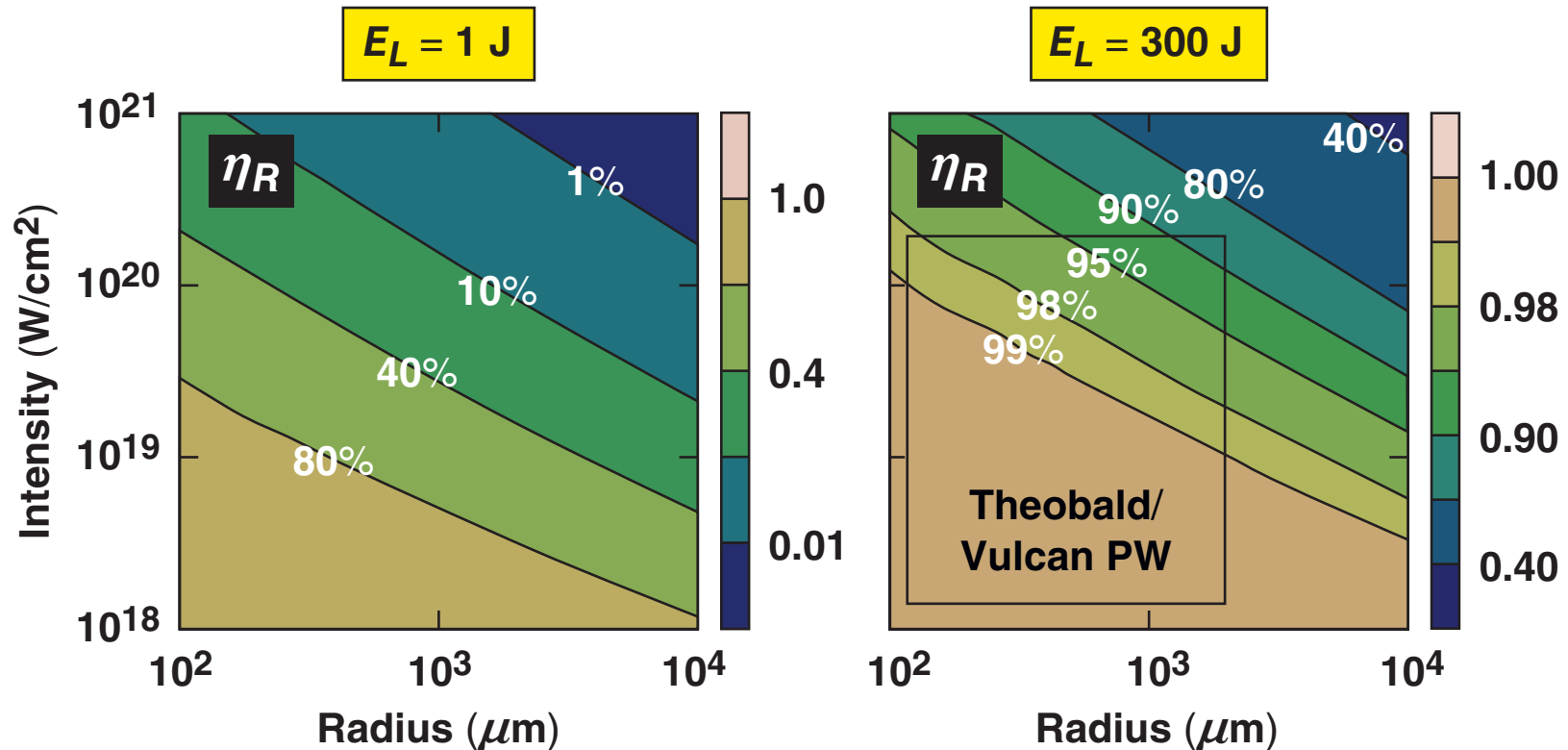
Pair creation due to the Trident process can be estimated since the cross section is well known



- Of the two mechanisms that are important for OMEGA EP parameters, the Trident process is dominant for targets thinner than a few hundred microns.
 - “Trident” process: $e^- + Z \rightarrow e^- + Z + e^+ + e^-$
- Probability of positron production (per electron) is calculated to be between $W_+ \simeq (10^{-4} \text{ to } 10^{-3})$ [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.



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



- For Au targets ($Z = 79$) greater than $\sim 100 \mu\text{m}$ thick, this process becomes competitive with Trident:



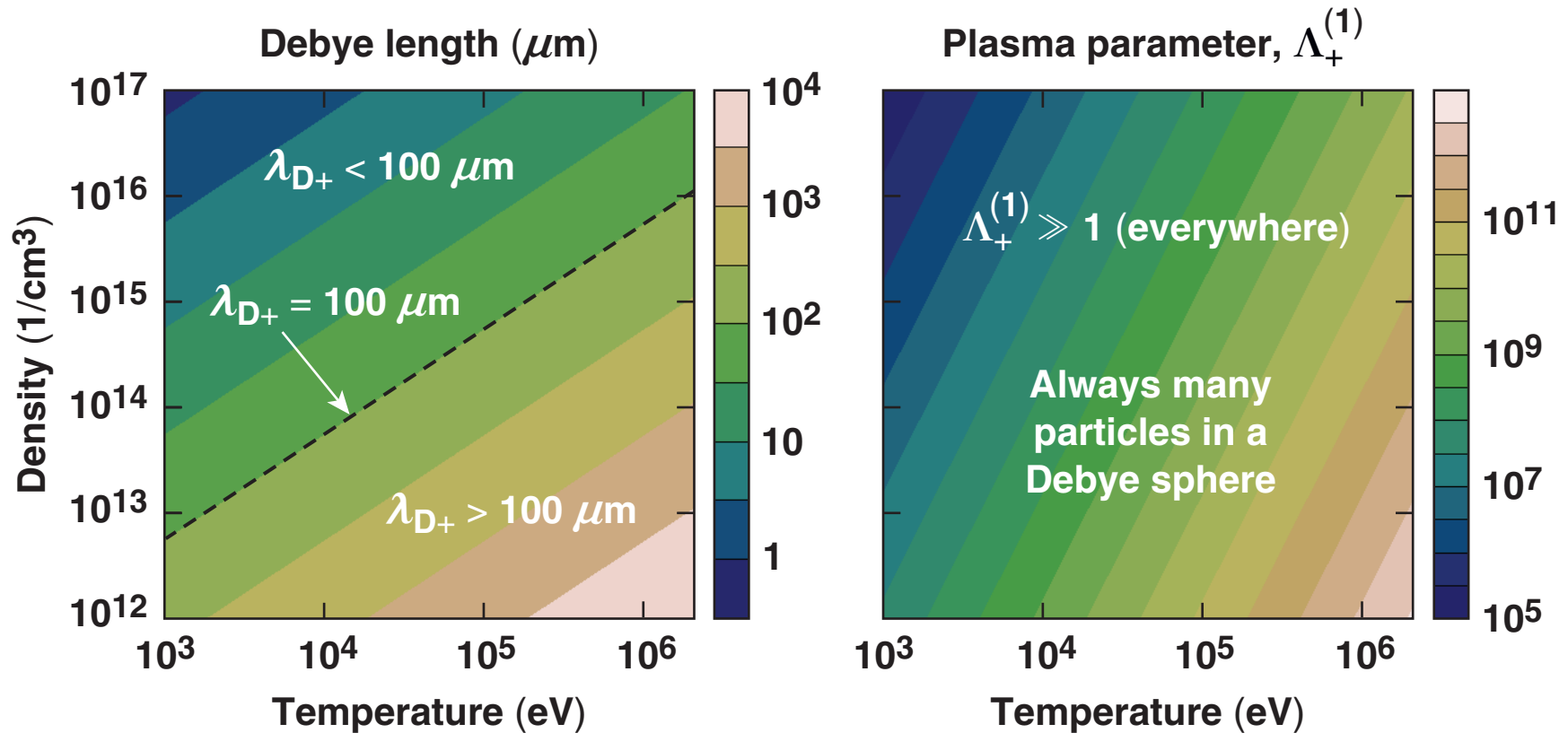
- The bremsstrahlung efficiency is well known ($E_\gamma > 1.02 \text{ MeV}$):

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

- 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 $x = 100 \mu\text{m}$

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: $\Lambda_+^{(2)} = \ell_{\text{system}} / \lambda_{D+} \gg 1$

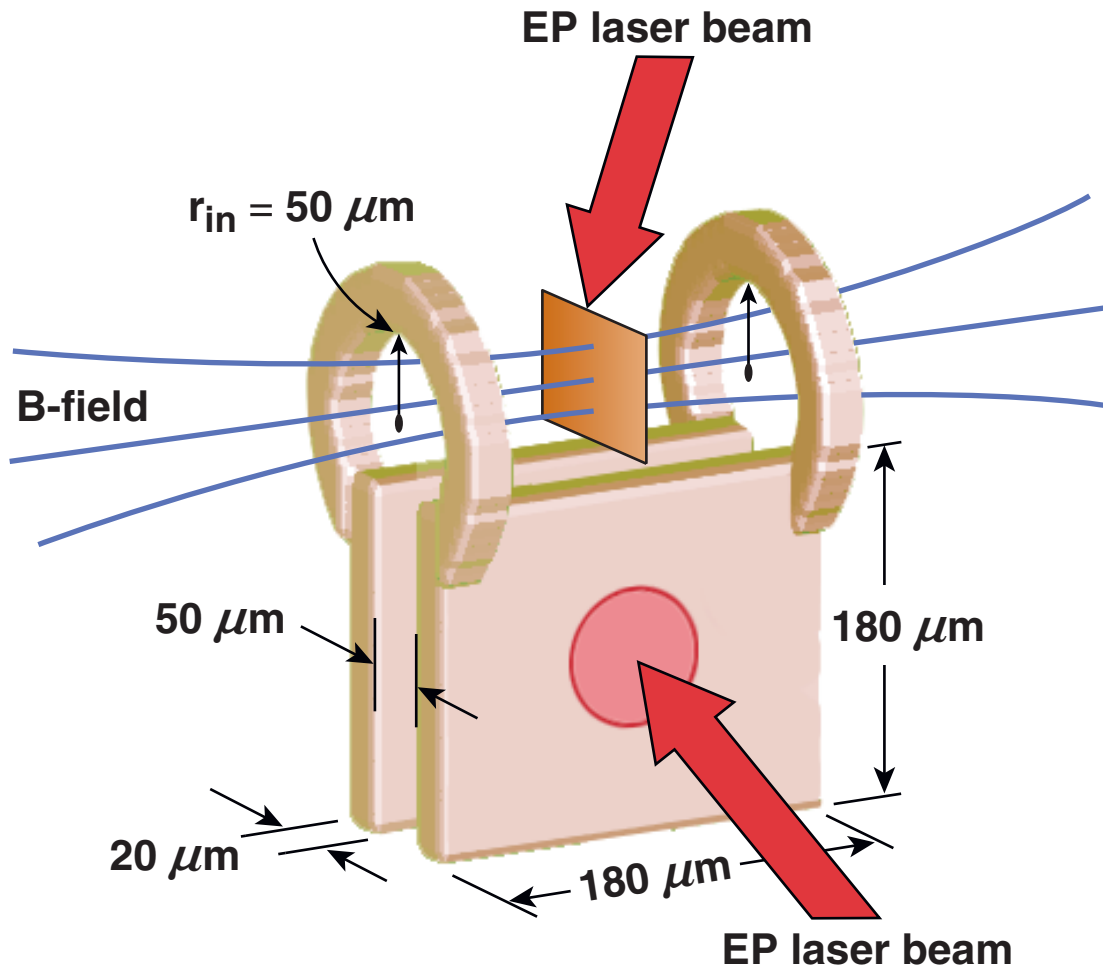


Positron expansion makes it difficult to obtain the required density of $\gtrsim 10^{16} \text{ cm}^{-3}$



- Unlike hot electrons, positrons do not reflux.
- Spherical expansion must be limited to a radius of $300 \mu\text{m}$,
 - 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*

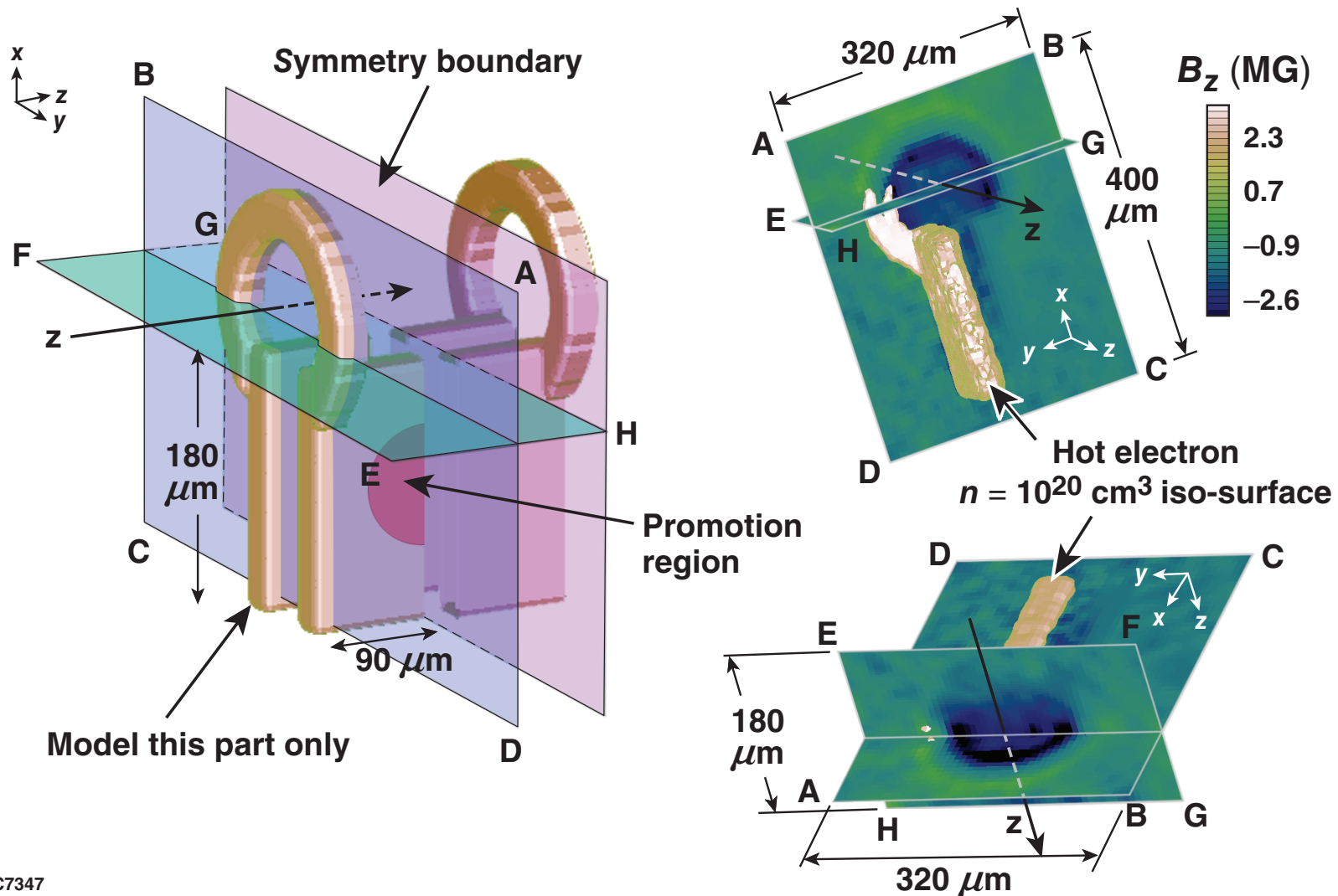
The flexibility of multiple EP beams can be utilized to magnetize a foil target



- 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).

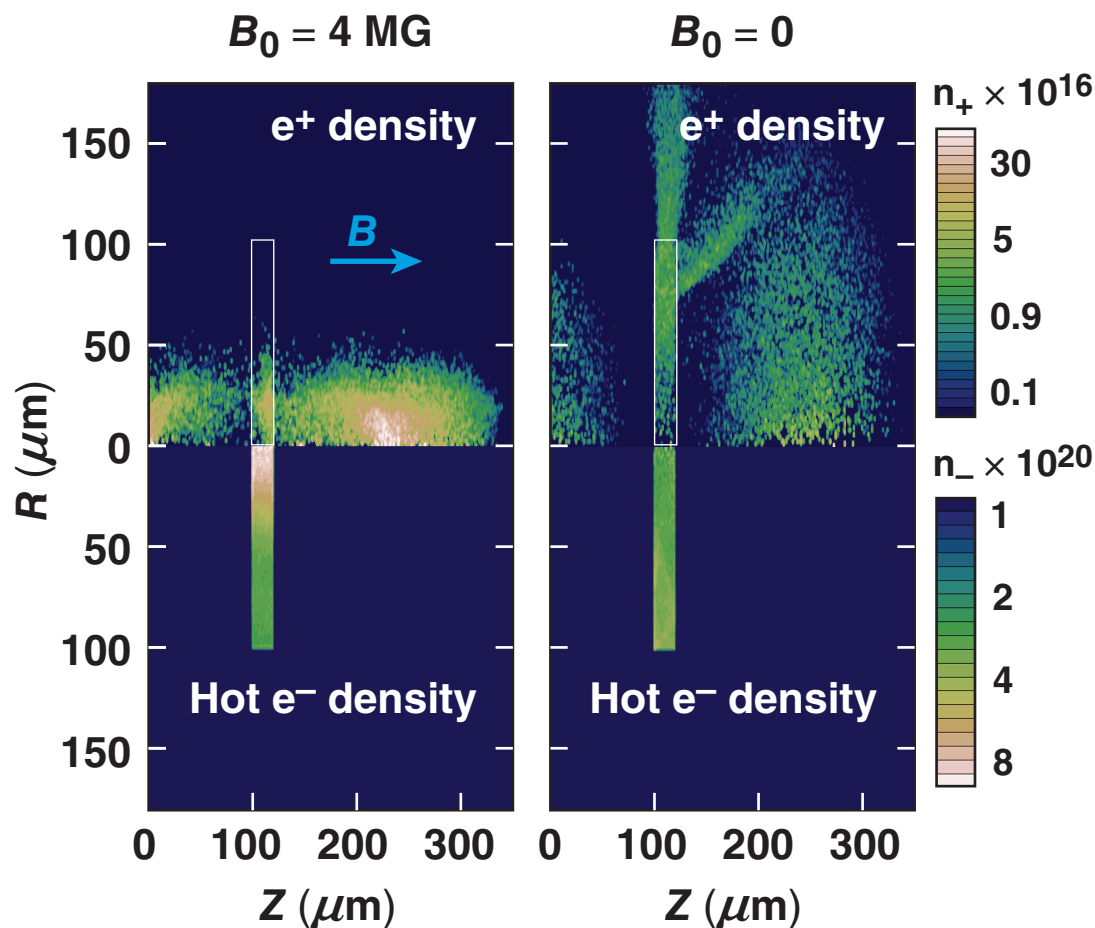
The first part of the scheme has been investigated with *LSP* indicating that MG magnetic field strengths can be obtained



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

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

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.

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 $>100 \mu\text{m}$
- The probe beam would need to be in the submillimeter range

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