# Positron generation and acceleration from a high-Z foil target
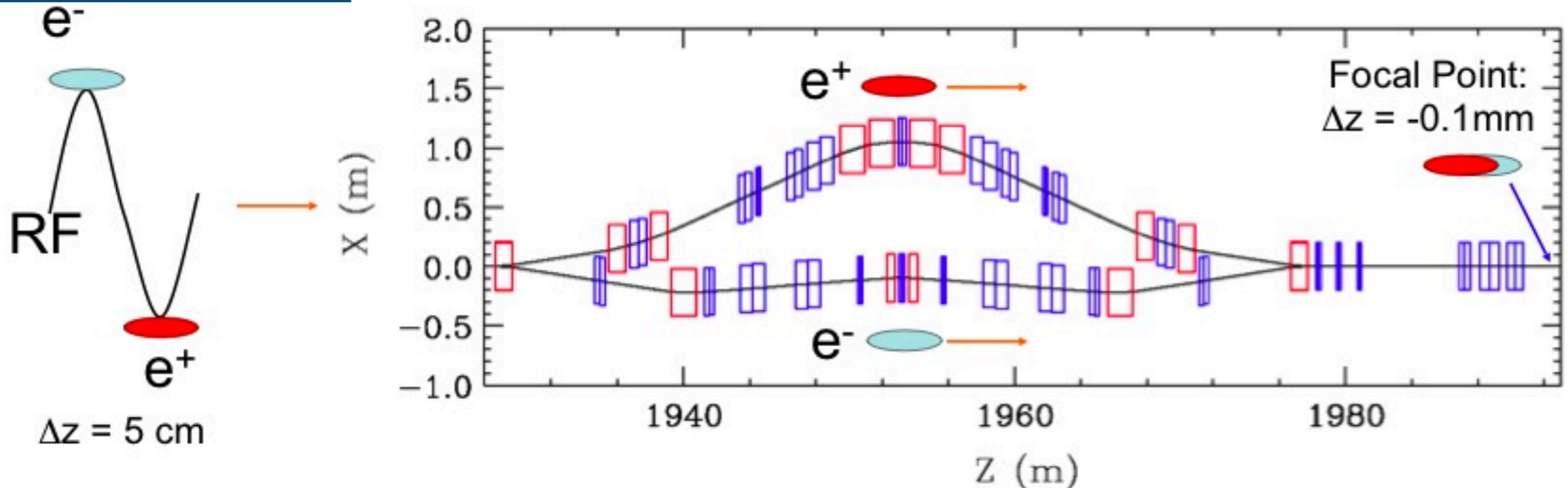
**FACET-II Science Workshop 2019**
**1:50~2:10  10/31/2019**

**Hiroki Fujii (Presenter), K.A. Marsh, C. Joshi**

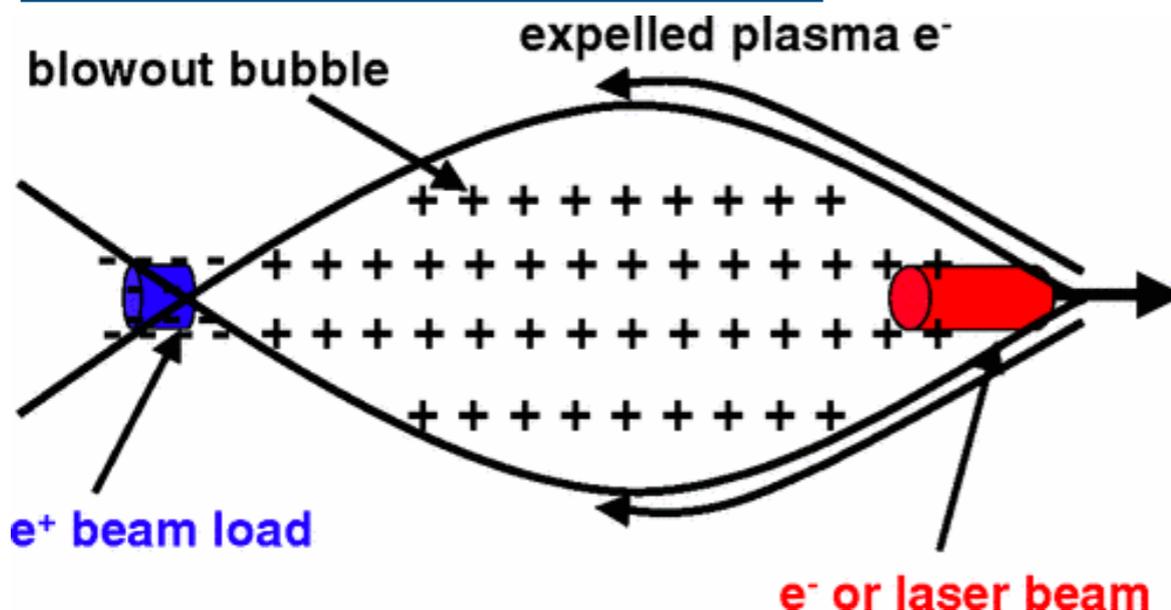**Contents pertinent to proposal No. E303**

# Acceleration of positrons using electron-beam-driven plasma wakefield

https://portal.slac.stanford.edu/sites/ard_public/facet/facilities/Pages/TwoBunchProduction.aspx
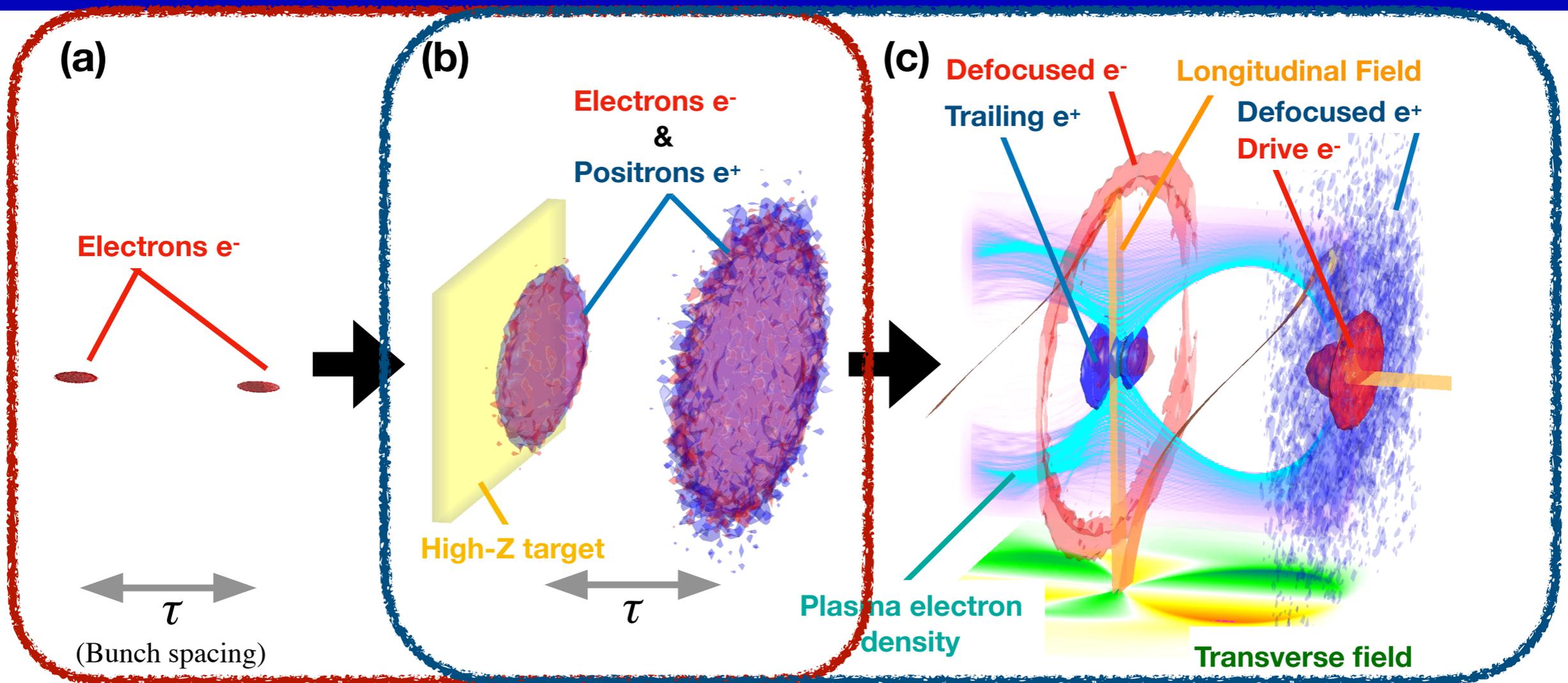
Electron-beam driven PWFA



- Sail-boat chicane experiment is proposed for an electron beam driven positron acceleration

- We will not have this setup in the next few years due to the availability of positron sources.

*X. Wang et. al, PRL 101, 124801(2008)

**(a)**

Electrons e⁻

$\tau$

(Bunch spacing)

**(b)**

Electrons e⁻
&
Positrons e⁺

High-Z target

$\tau$

**(c)**

Defocused e⁻

Trailing e⁺

Longitudinal Field

Defocused e⁺

Drive e⁻

Plasma electron density

Transverse field

**Geant4 simulation**

- E303 proposal. The goals are

**QuickPIC (Particle-in-Cell) run
for 6D phase space output of Geant4**

1. Characterize the drive electrons and secondary e⁻-e⁺ pairs. Compare the Geant4 result with the experimental result

2. Observe the acceleration signature in the positron spectrum

3. Accelerated energy spectrum with a sharp peak

# Positron acceleration experiment using high-Z target (E303)

**(a)**

**(b)**

**(c)**



Electrons e⁻

$\tau$

(Bunch spacing)

High-Z target

Electrons e⁻
&
Positrons e⁺

$\tau$

Defocused e⁻

Longitudinal Field

Trailing e⁺

Defocused e⁺

Drive e⁻

Plasma electron density

Transverse field
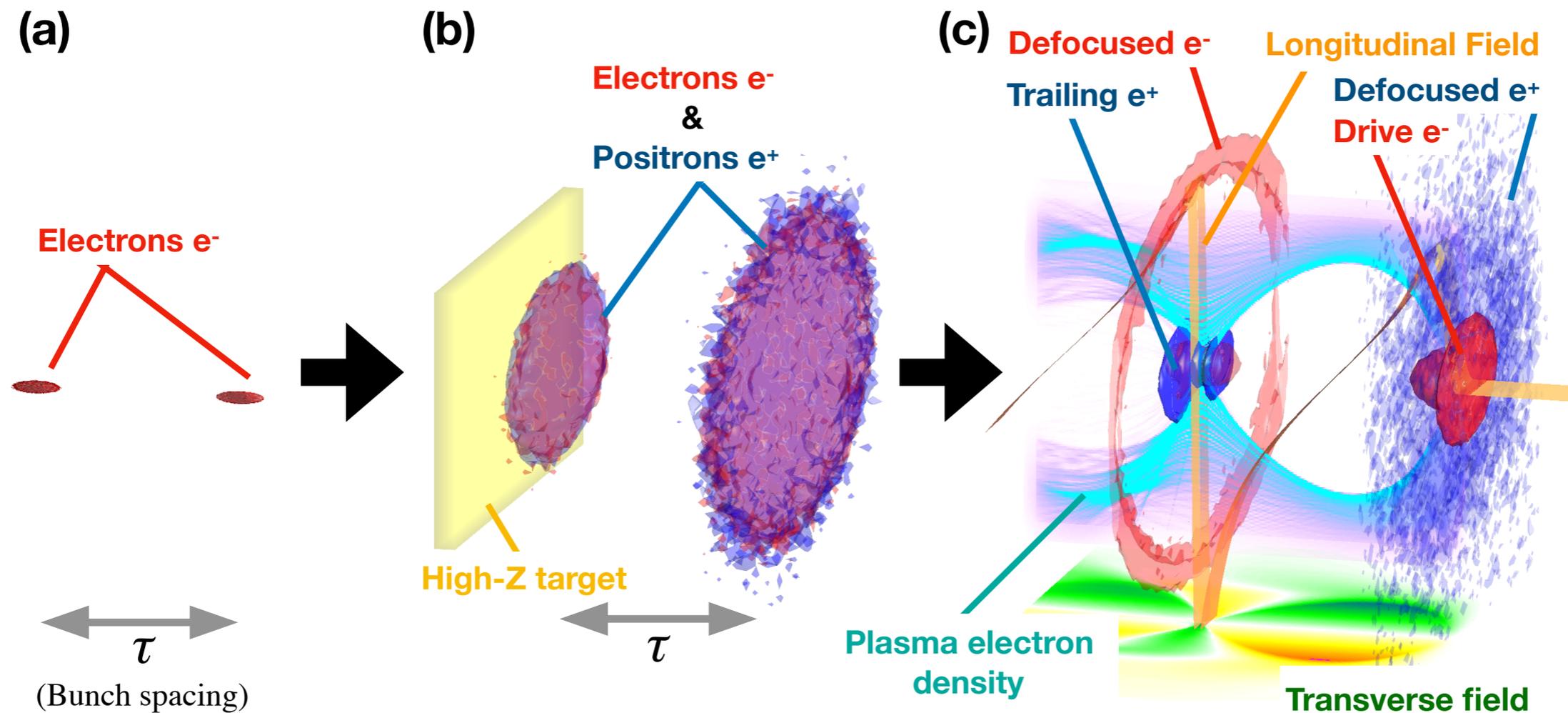
- However, the high-intensity electron beam's interaction with the solid target is not covered by the Geant4 simulation.
  - ionization of the solid material, duration of the effect (1 bunch or 2 bunches)
  - Collective effects such as filamentation instabilites, CTR across the boundary

**Characterize the drive beam and positron characteristic beforehand**

# Expected positron yield and spectrum from Tantalum

- The spectrum is continuous. Low energy positrons have high divergences

- Expect to have acceleration peak in 0.5~3.0 GeV

  - Interested in coffin chamber diagnostic

- Don't expect low transverse emittence



Initial distribution spectrum (solid line) limited by half angle (dashed line)
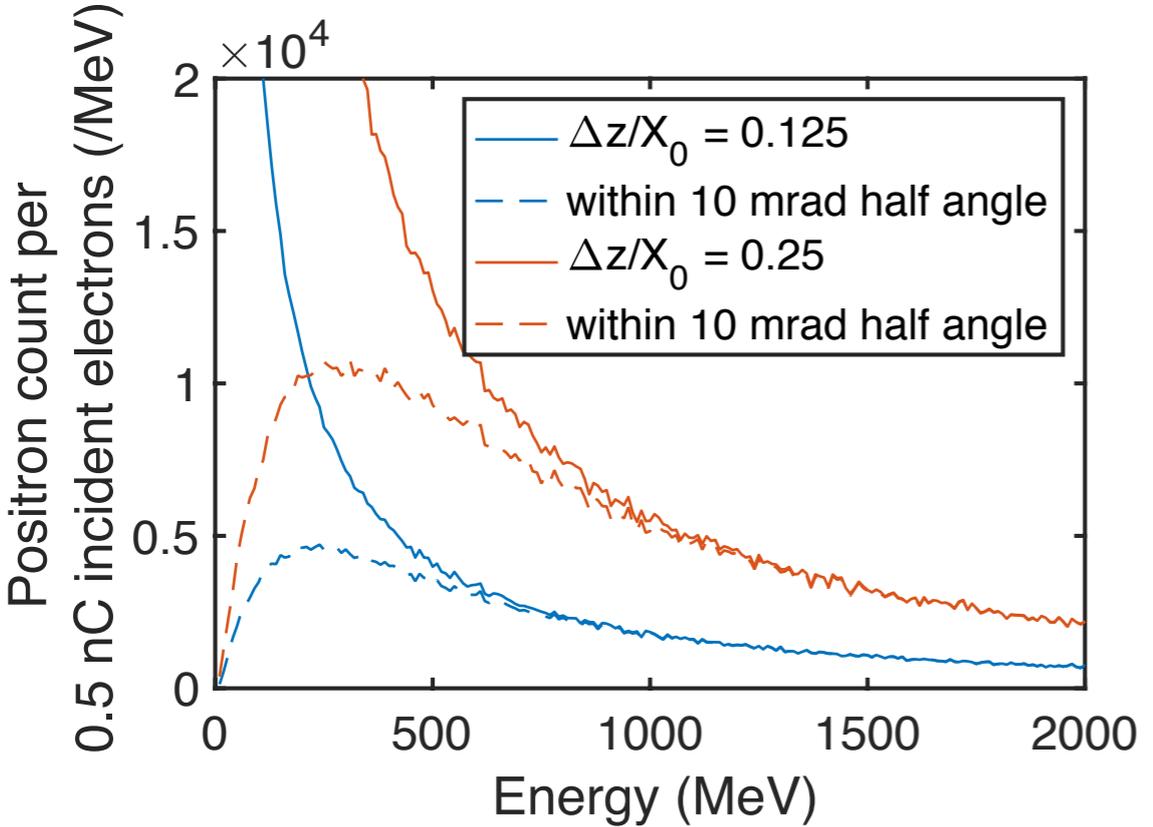
Example of accelerated spectrum limited by the acceptance
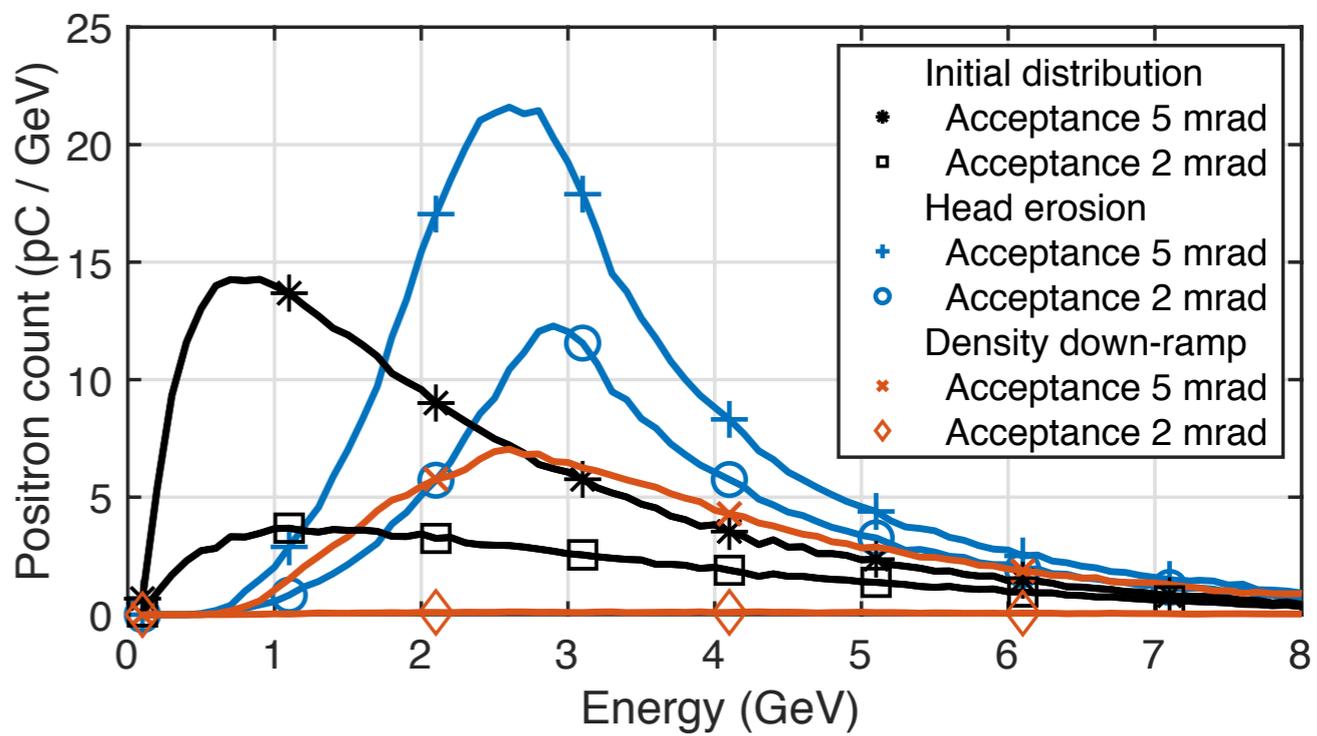
Beam parameters in H. Fujii, et. al., PRAB2019

# Diagnostics needed in the initial phase

- Target setup

    - Inside picnic box as part of the E305

- Driver electron beam emittance and spectrum before and after the foil target will be measured as in E300

    - TCAV, EOS, LFOV, Cherenkov spectrometer

- Pair produced positron characteristics

    - Coffin chamber and dump table

**Measure drive electron & positron characteristics dependence as part of E305 experiment**

1.  Assess foil damage and raster conditions for several beam spot size and target thickness parameters.

2.  Measure emittance growth and energy loss of the drive beam.

3.  Look for signatures of beam filamentation, or any anomalous from the Geant4 results such as beam divergence, gamma spectra, gamma spatial characteristics, and changes in the positron yield etc.

4.  Measure the initial positron beam characteristics at dump table and coffin chamber such as, energy spectra, emittance and divergence. This requires the quads and dipole to collect and measure positrons above 500 MeV with an rms collection angle of 10 mrad.

# Run plan in the Initial phase of E303 ②

- **Repeat the same procedures for the drive & trailing pair setup**

  - The trailing signal changes if the drive beam modifies the target (damage, ionization, etc)

  - Deviation from the geant4 result in trailing beam will also affect the positron production characteristics

Drive and trailing energy spectrum
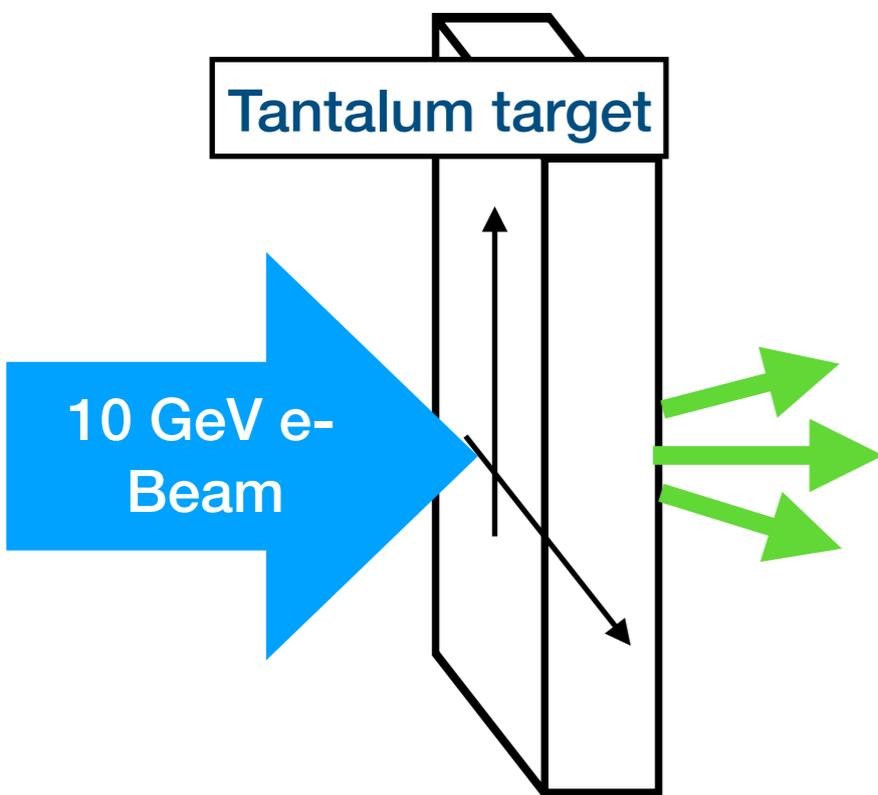after tantalum foil target
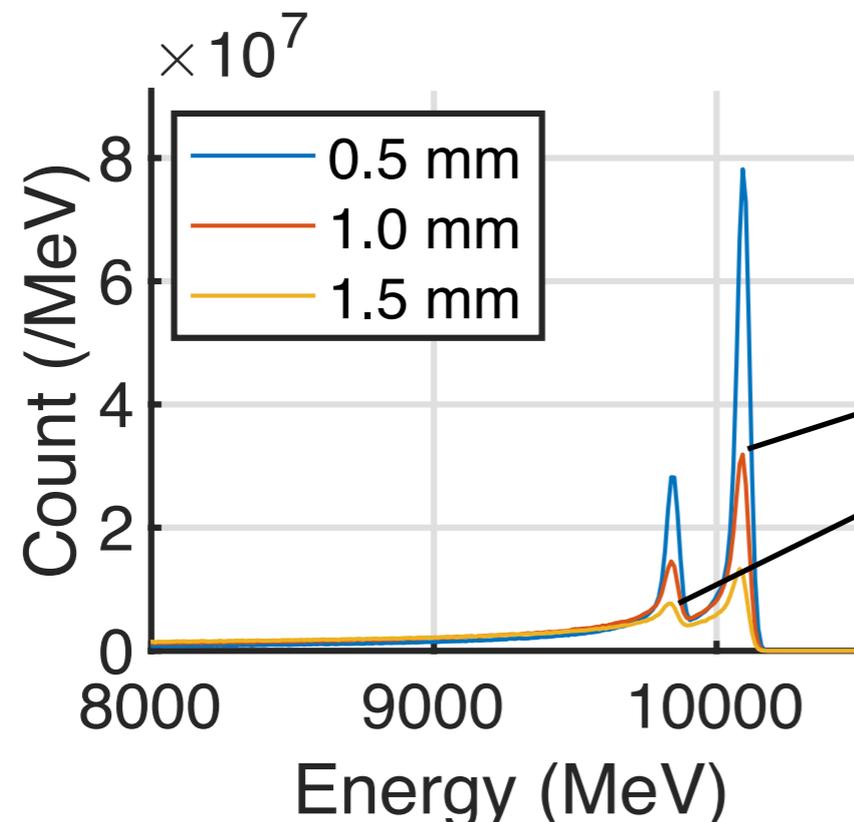
**Beam parameters**
**Driver : 1.6 nC, 10.1 GeV, $\Delta E/E$ = 0.2 %**
**Trailer : 0.5 nC, 9.8 GeV, $\Delta E/E$ = 0.2 %**
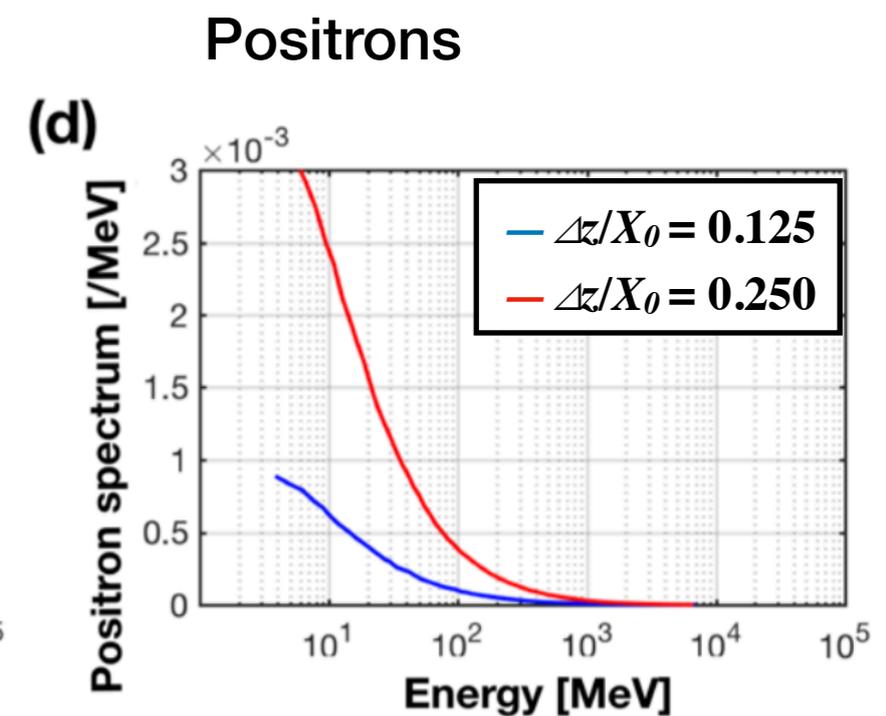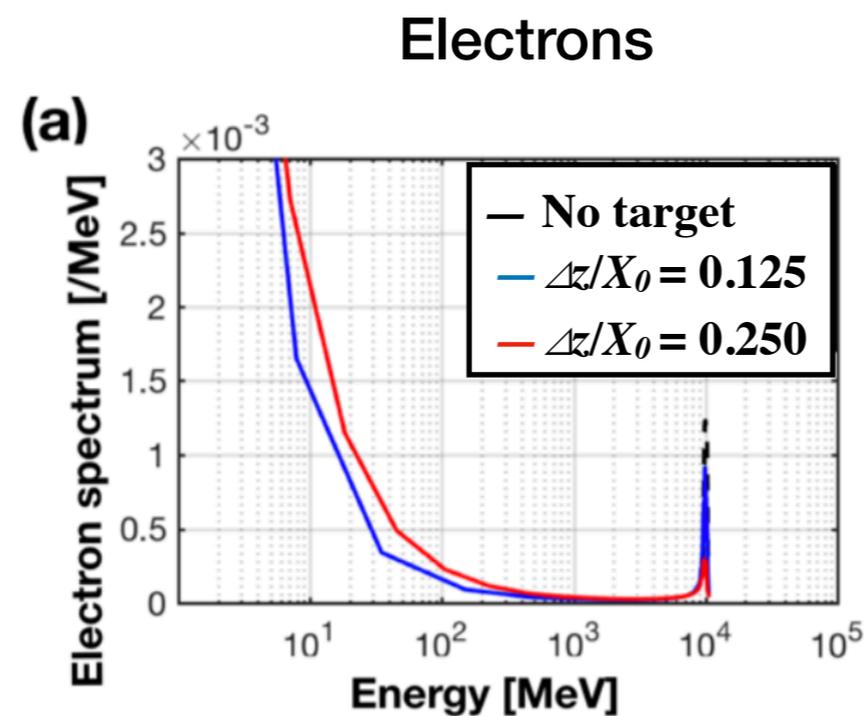
# Typical Monte-Carlo simulation result

- The beam is assume to be focused on the surface
- Particle information fetched at the back surface of the foil



Tantalum target

10 GeV e-Beam

**Thickness :** $\triangle z$

**Radiation length :** $X_0$ (=4.094 mm for Ta)

Energy spectrum probability per one 10 GeV incident electron
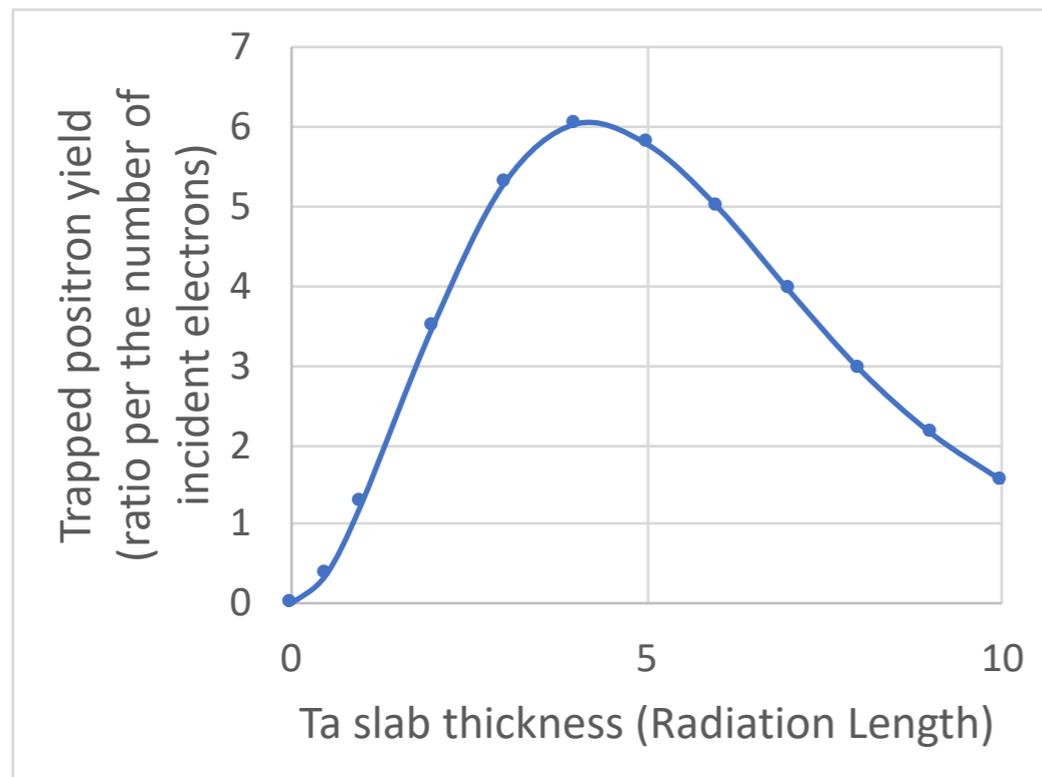
Electrons

Positrons
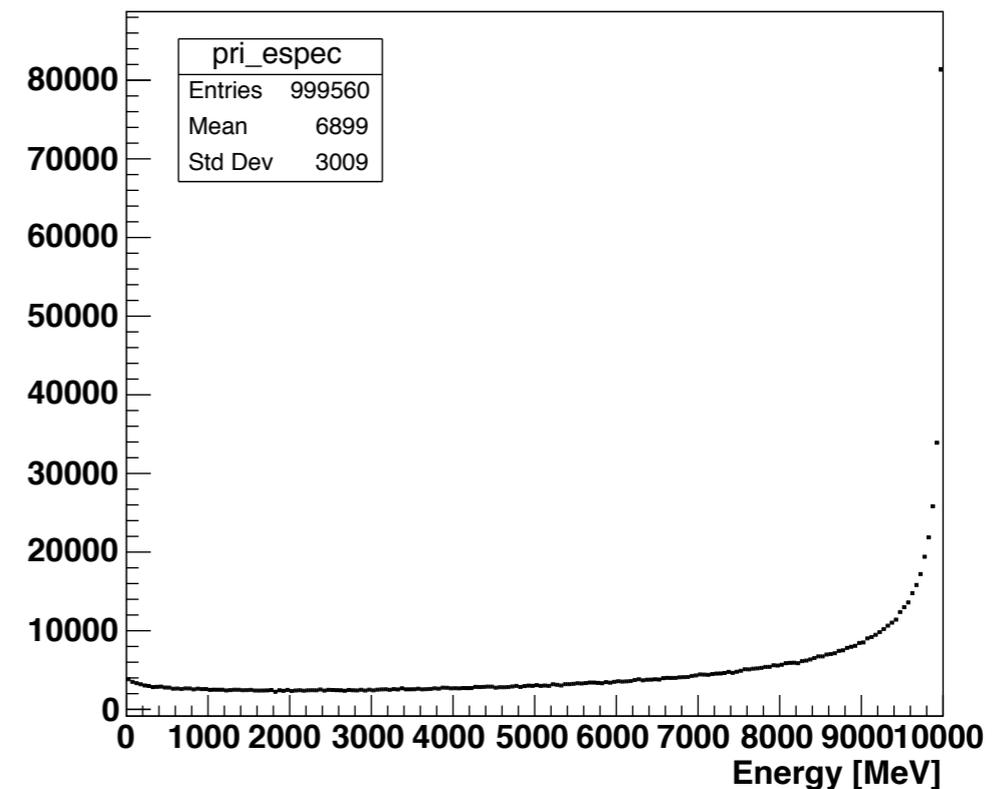
AAC2018, H. Fujii, et. al. (2018)

# Positron characteristics on Geant4

- Positron yield linearly scales as the thickness gets larger
- Radiation length : Mean Initial beam energy decreases exponentially as $\exp(-\Delta z/L_{RL})$
- Positron beam (> 10 MeV) emittance depends on the thickness and beam spotsize

Positron yield dependence on thickness

Driver beam energy spectrum after 1.5 mm ( ~ 0.37 $L_{RL}$) of Tantalum



NOTE : Counted particles more than 10 MeV

The drive beam energy no longer has an original energy

**0.5 mm and 1 mm tantalum foils are considered**

# Positron characteristics on Geant4

- Positron yield linearly scales as the thickness gets larger
- Radiation length : Mean Initial beam energy decreases exponentially as $\exp(-\Delta z/L_{RL})$

- Positron beam (> 10 MeV) emittance depends on the thickness and beam spotsize.

  - Figures below show the incident electron beam parameter dependence
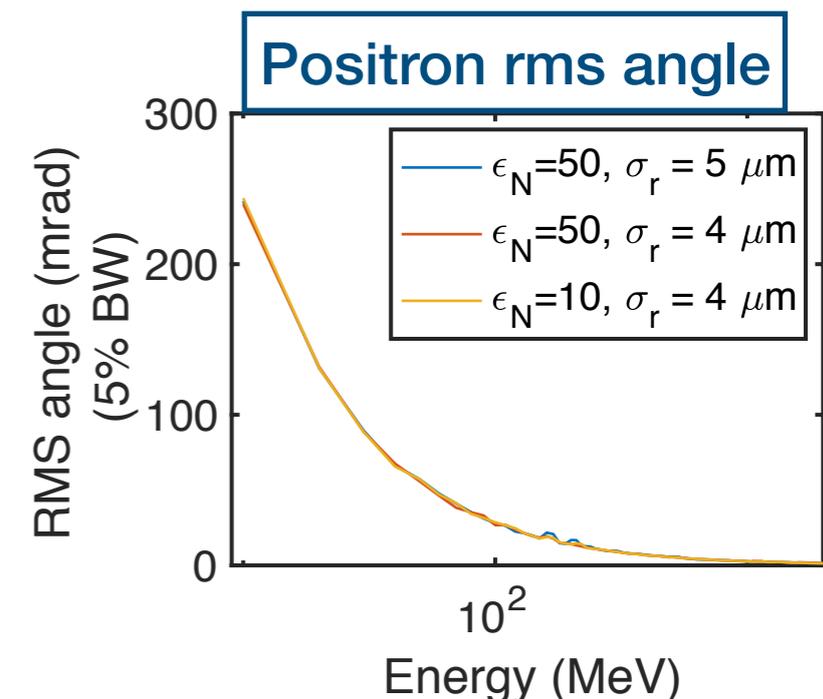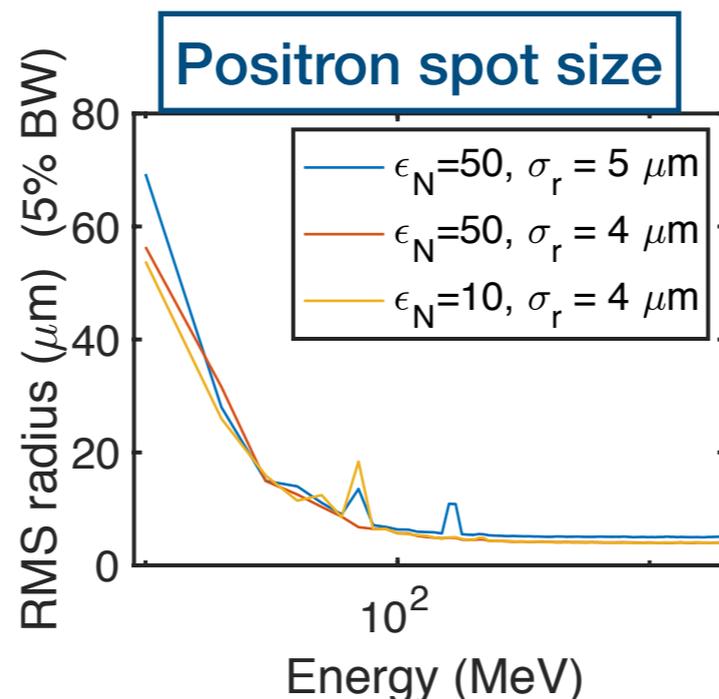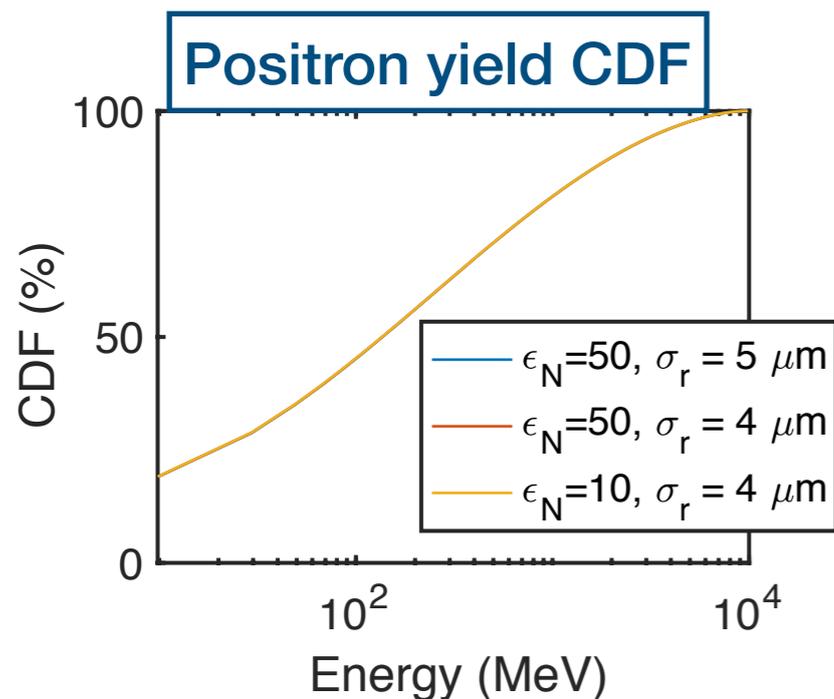


**Observations:**
- **50 % of positrons are above 100 MeV, which is going to be captured by the wake**
- **High energy positrons outgoing from the foil retains the same spotsize.**
- **Angle doesn't depend on the initial emittance and spot size.**
  **Therefore, initial spotsize is the decisive parameter for the capture efficieny**

# Requirement for the drive beam after the foil

- Not intense enough to make a hole to the target in several shots (experiment in E305)
- Beam transmitted through the foil can ionizes neutral gas species
  - No plans to pre-ionize plasma because the high-Z converter blocks the laser path.
- Low enough emittance so that it can propagate long enough distance for a given thickness to be able to observe the acceleration signature for positrons

Coulomb scattering formula

$$\theta = \frac{13.6\text{MeV}}{\gamma}\sqrt{\frac{\Delta z}{X_0}}\left[1 + 0.0038\ln\left(\frac{\Delta z}{X_0}\right)\right]$$

$$\varepsilon^2 = \varepsilon_0(\varepsilon_0 + \underline{\beta_0\theta^2})$$
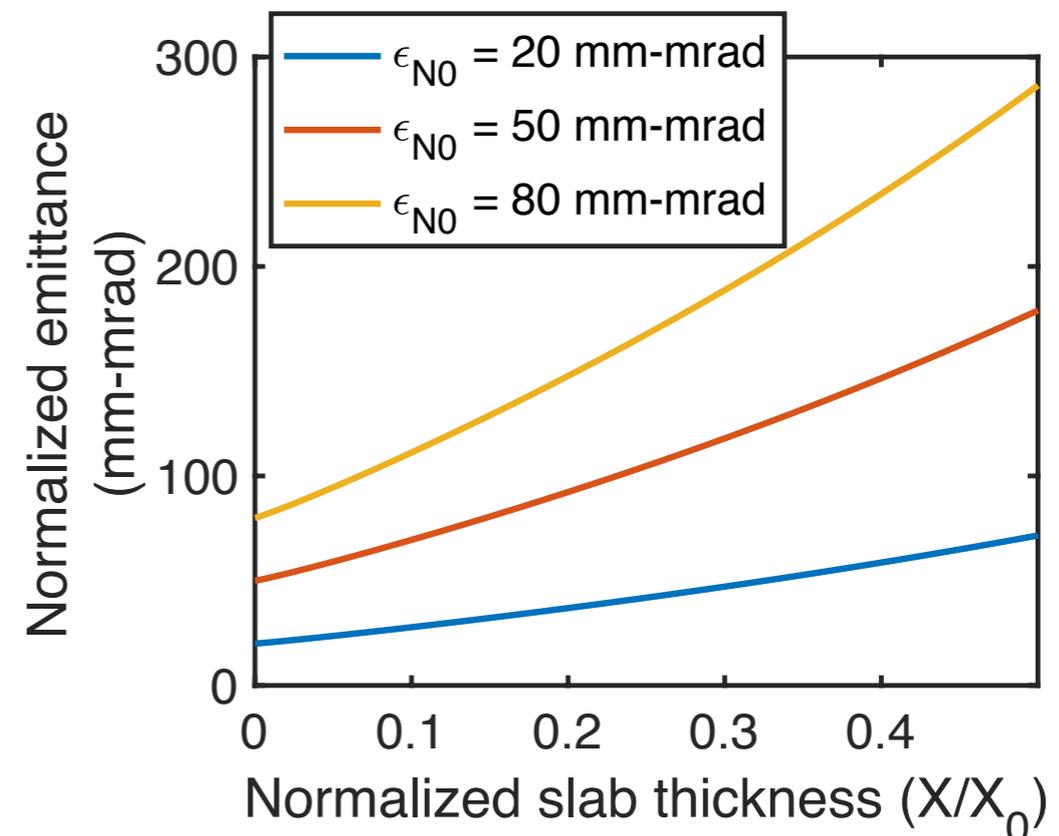
**Emittance growth due to the target thickness**

$X_0$ : Radiation length

$\Delta z$ : Target slab thickness
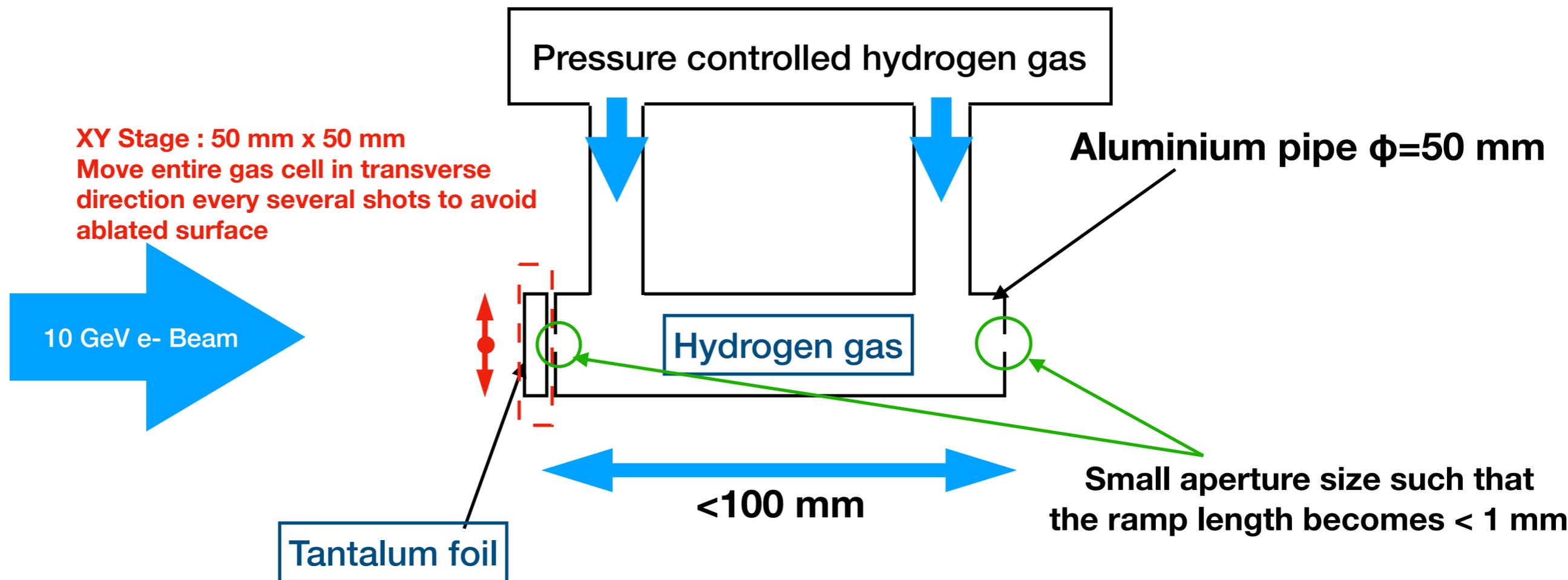
$\varepsilon_0$ : Initial normalized emittance

**Emittance after the foil further grows when beam is not fully focused**

Emittance growth dependence on target thickness.
(Suppose beam focused on the target surface)

# Single bunch experiment using Hydrogen

- Later we will study the interaction between the foil and plasma boundary
- Confirmed single bunch configuration parameter by Glen ionizes hydrogen
- Parameter study by changing beam spot size, plasma density, charge per unit length etc.



Pressure controlled hydrogen gas

Aluminium pipe φ=50 mm

XY Stage : 50 mm x 50 mm
Move entire gas cell in transverse direction every several shots to avoid ablated surface

10 GeV e- Beam

Hydrogen gas

<100 mm

Small aperture size such that the ramp length becomes < 1 mm

Tantalum foil

Allow gas leak at the each end of gas cell
Pros : Least effort to make the target movable and replaceable.
        Foil doesn't degrade.
Cons : We would still see some effect of density ramp.
        Higher ionization potential compared to Li

# Thank you for your attention

## Acknowledgement

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