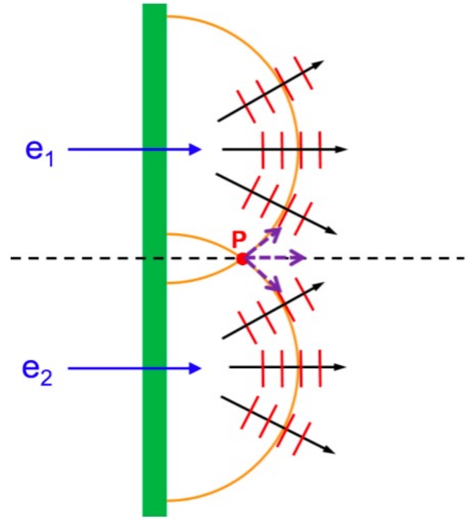
实验物理中心2022年（5-8月）研究生考核报告

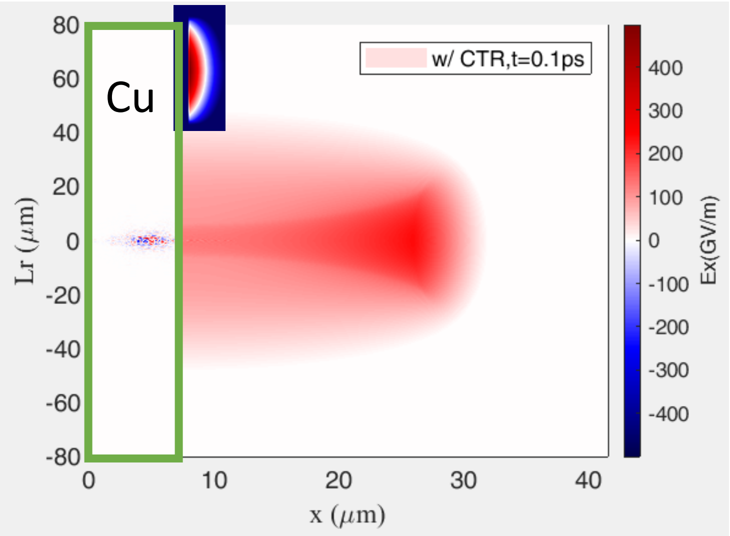
汇报人：司梅雨

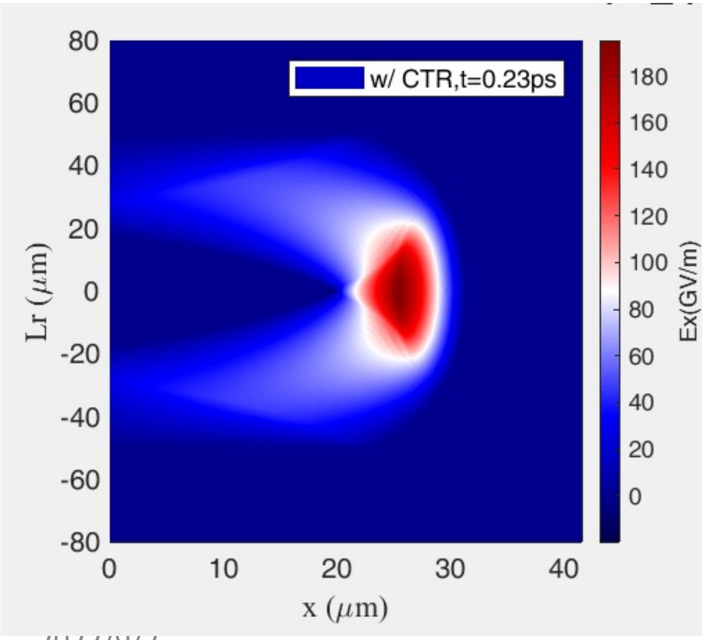
导师：阮曼奇/黄永盛

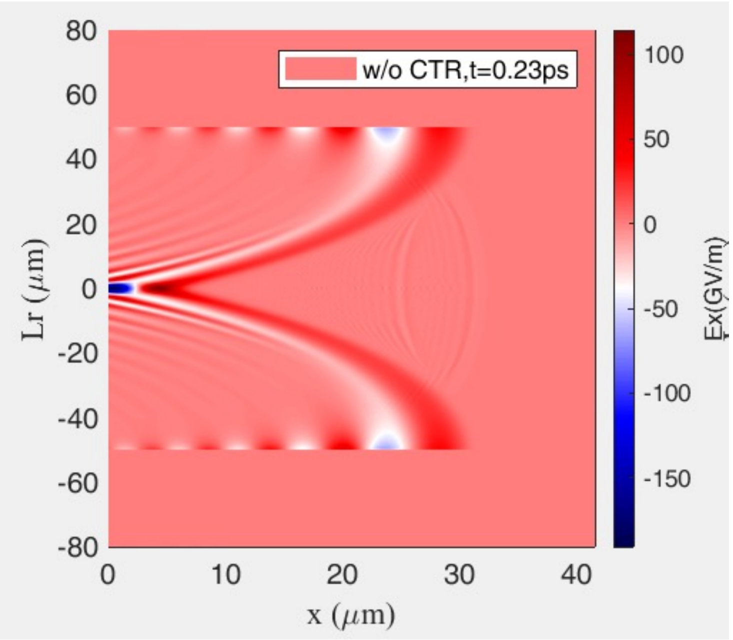
Positron acceleration with coherent transition radiation(CTR) in a dense plasma-channel

CTR









一. The radiation field distribution in the dense plasma-channel is solved

The longitudinal and transverse fields for $0 < y < d$ are as follows:

$$a_{x0} = a_0 \cos\sqrt{-k_x^2+1-\omega_{pei}^2}(y)e^{-i(\omega_L t-k_x x)}, 0<y<r,$$

$$a_{y0} = \frac{-ik_x}{\sqrt{-k_x^2+1-\omega_{pei}^2}} a_0 \sin\sqrt{-k_x^2+1-\omega_{pei}^2}(y)e^{-i(\omega_L t-k_x x)}, 0<y<r,$$

$$a_{x1} = a_1 \cos\sqrt{1-k_x^2}(y)e^{-i(\omega_L t-k_x x)}, r<y<d,$$

$$a_{y1} = \frac{-ik_x}{\sqrt{1-k_x^2+1}} a_1 \sin\sqrt{1-k_x^2}(y)e^{-i(\omega_L t-k_x x)}, r<y<d,$$

$$a_{x2} = a_2 e^{-\sqrt{k_x^2-1+\omega_{pe0}^2}(y-d)}e^{-i(\omega_L t-k_x x)}, y>d,$$

$$a_{x2} = \frac{-ik_x}{\sqrt{k_x^2-1+\omega_{pe0}^2}} a_2 e^{-\sqrt{k_x^2-1+\omega_{pe0}^2}(y-d)}e^{-i(\omega_L t-k_x x)}, y>d.$$

Considering the continuity of the longitudinal field and transverse field at $y = r$ and $y = d$, the relationship can be obtained.

$$a_{x1}|_{y=r(r<y<d)} = a_{x0}|_{y=r(0<y<r)},$$

$$a_{y1}|_{y=r(r<y<d)} = (1-\omega_{pei}^2)a_{y0}|_{y=r(0<y<r)},$$

$$a_{x1}|_{y=d(r<y<d)} = a_{x2}|_{y=d(y>d)},$$

$$a_{y1}|_{y=d(r<y<d)} = (1-\omega_{pe0}^2)a_{y2}|_{y=d(y>d)}.$$

$$z_1 = \frac{\tan\sqrt{1-k_x^2}(r)}{\sqrt{1-k_x^2}} = \frac{(1-\omega_{pei}^2)\tan\sqrt{-k_x^2+1-\omega_{pei}^2}(r)}{\sqrt{-k_x^2+1-\omega_{pei}^2}} = z_2,$$

$$\tan\sqrt{1-k_x^2}d = \frac{(\omega_{peo}^2-1)\sqrt{1-k_x^2}}{\sqrt{k_x^2-1+\omega_{peo}^2}}.$$

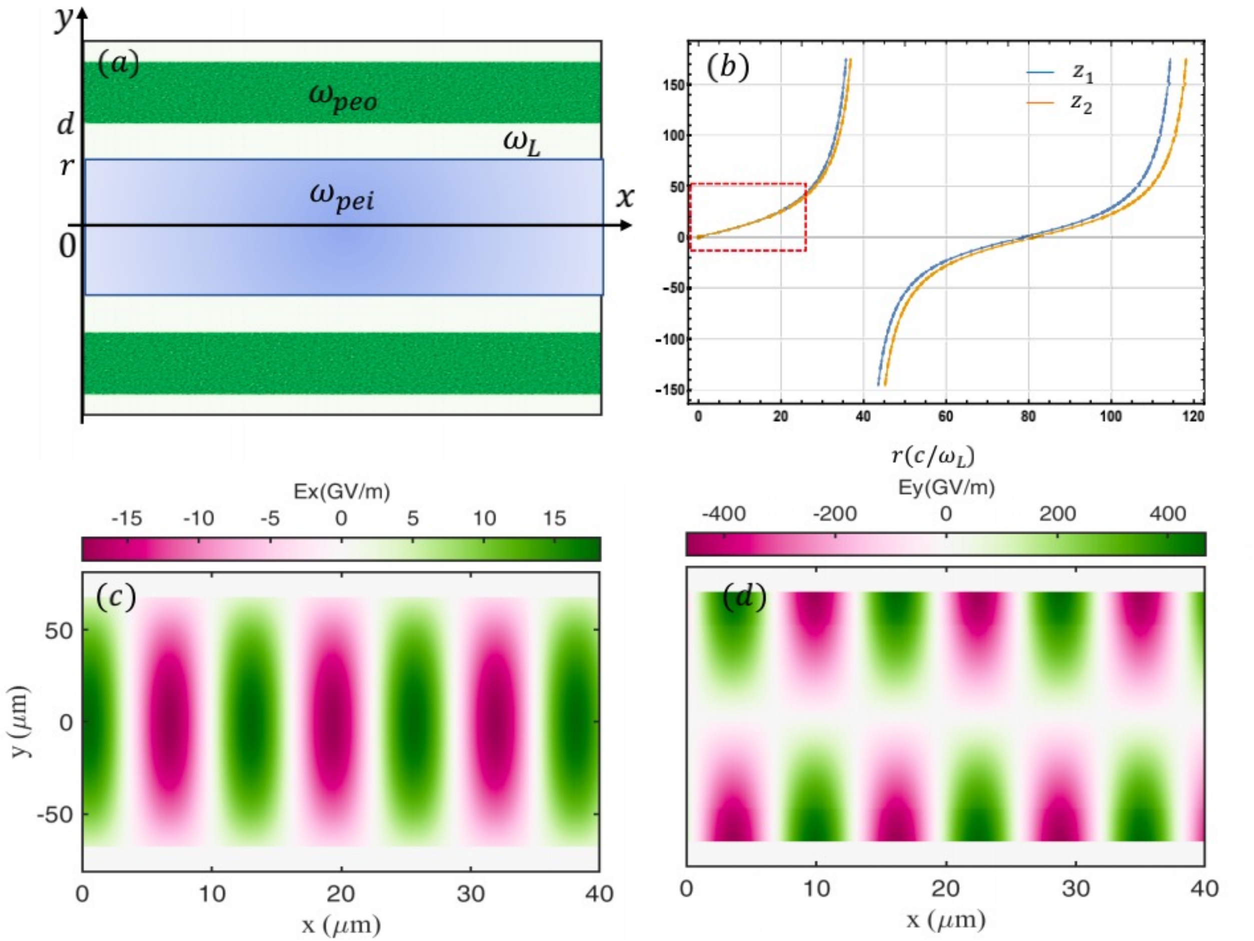


FIG. 1. (a) shows the propagation of the terahertz waves in the x direction in a dense plasma-channel. ω_{pei} is the plasma frequency of the relativistic electron beam with the energy of 1GeV. For r<y<d, the terahertz waves propagate in the vacuum. ω_{peo} corresponds to the outer dense plasma-channel. (b) shows the solution of r in Eq.(2). The range of r is 0 to $25(c/\omega_r)$, which is shown in the red rectangle. (c) and (d) are shown the two-dimensional distribution of the longitudinal electric field and the transverse electric field. The periodically distributed fields are formed in the plasma-channel to longitudinally accelerate and transversely focus of the positrons at a specific phase. In here, we taking the values of coefficient a_1 equal to 0.5×10^{-15}, and $k_x = 0.9992(k_L)$, $r = 25(c/\omega_L)$, $d = 34(c/\omega_L)$.

二. Two-dimensional particle-in-cell (PIC) simulation (Epoch2D)

The 1GeV electron bunch can make 30MeV positron bunch reach the maximum cut-off energy of 2.3GeV in 700ps.

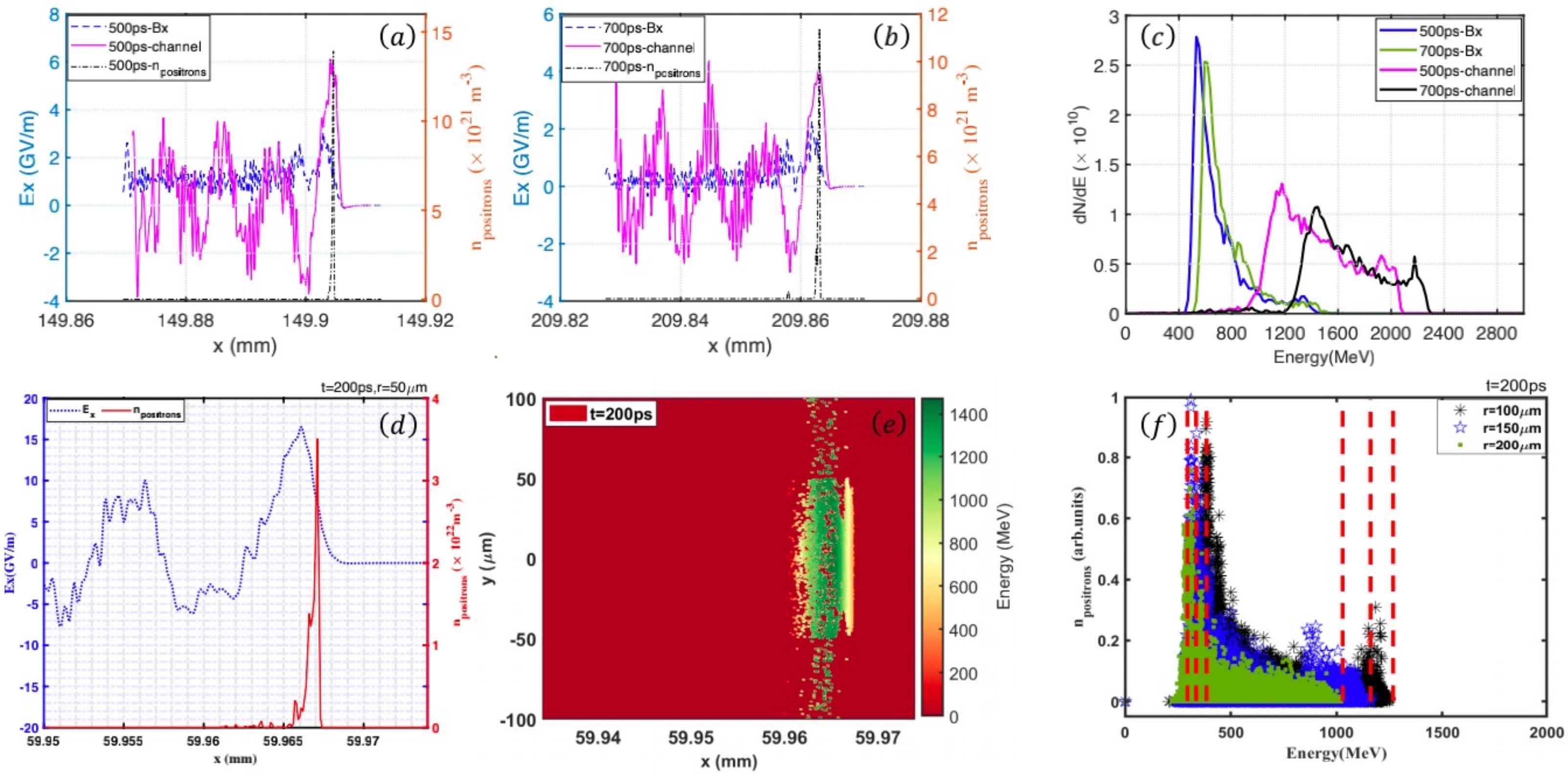
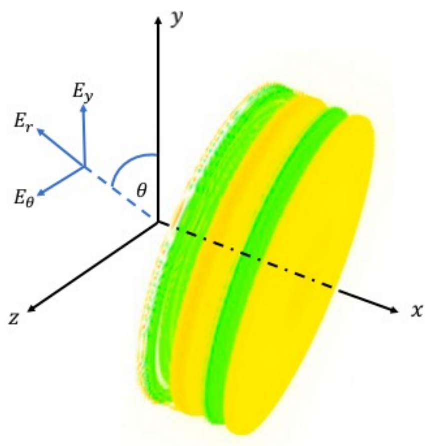


FIG. 2. (a)-(b) show the longitudinal acceleration field of the external magmetic field B_x and the dense plasma-channel. The periodically distributed fields are formed in the plasma-channel. The field in the area where the positrons are located is 3-4 times larger than that without the plasma-channel. (c) shows the evolution of energy spectrum of positrons under two conditions. (d)-(e) show that the accelerated phase of the positrons. It is mainly divided into two parts. The energy corresponding to the positrons in the front part is about 0.5Gev-1GeV, and the positrons in the rear part has a higher energy, corresponding to 1GeV-1.5GeV. Therefore, in the acceleration process, there is a longitudinal compression effect. (f) shows the energy spectrum of positrons at t = 200ps for the radius of the plasma pipe of 100μm, 150μm, and 200μm. With the increase of the dense plasma-channel radius, the peak energy and maximum cut-off energy of positrons decrease.

三. Cylindrical particle-in-cell (PIC) simulations (Smilei)

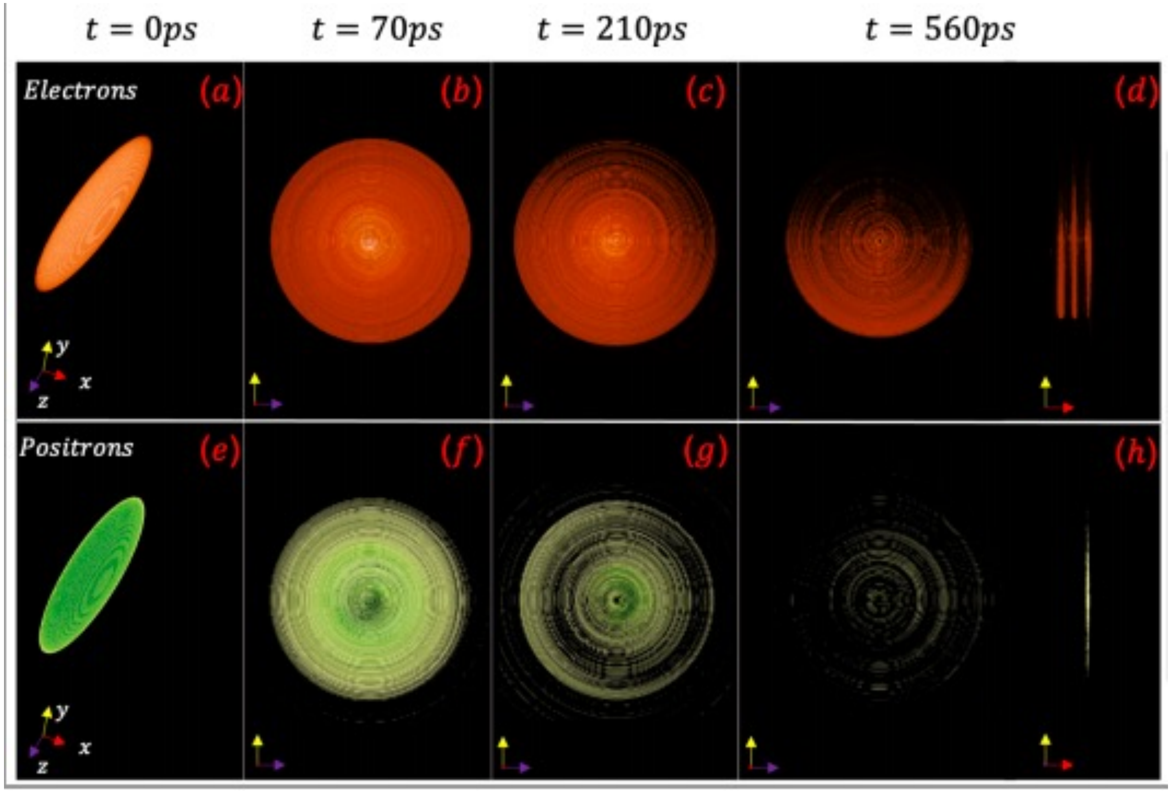


The field is subjected to a Fourier series decomposition in cylindrical coordinates:

$$F(x,r,\theta) = \Re\left[\sum_{m=0}^{+\infty} \tilde{F}^m(x,r)\exp(-im\theta)\right]$$

$$= \tilde{F}^0_{real} + \tilde{F}^1_{real}\cos(\theta) + \tilde{F}^1_{imag}\sin(\theta) + \tilde{F}^2_{real}\cos(2\theta) + \tilde{F}^2_{imag}\sin(2\theta) + \cdots,$$

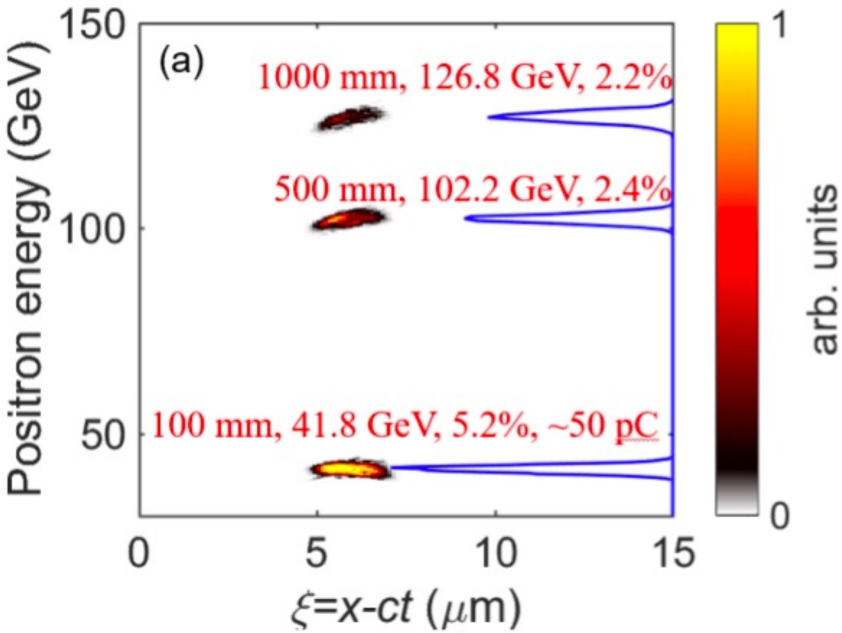
Parameters	Values
Moving window	
Size	$x \times L_r = 41.6\mu m \times 80\mu m$
Cell length	$dx = 0.1\mu m$; $dr = 0.25\mu m$
Electron beam	
Maximum density (n_e)	$3 \times 10^{24} m^{-3}$
σ_{xe}	$3\mu m$
σ_{re}	$26.9\mu m$
Energy	1GeV
Temperature($m_e c^2$)	[x,y,z]=[0.01,0.001,0.001]
Positron beam	
Maximum density ($n_{positron}$)	$6.5 \times 10^{21} m^{-3}$
σ_{xp}	$3\mu m$
σ_{rp}	$25.5\mu m$
Energy	30MeV
Temperature($m_e c^2$)	[x,y,z]=[0,0,0]



The peak energy of positron bunch can reach 1.4GeV with the rms energy spread of 9.8% in the cylindrical simulations.

Positron acceleration by terahertz wave and electron beam in plasma channel

Zhangli Xu[1], Baifei Shen[1,*], Meiyu Si[2,3], Yongsheng Huang[2,4]



By two-dimensional simulation, we demonstrate the acceleration of positrons from initial 1 GeV to 126.8 GeV with a charge of ~10 pC over a distance of 1 m. The energy spread of accelerated positrons is 2.2%.

总结与展望

1. The radiation field distribution in the dense plasma-channel is solved and the reference value of the channel radius is given.
2. The two-dimensional PIC simulation show that the positron accelerating field of the dense plasma-channel is 3-4 times larger than that the external magnetic field. The 1GeV electron bunch can make 30MeV positron bunch reach the maximum cut-off energy of 2.3GeV in 700ps.
3. The peak energy of positron bunch can reach 1.4GeV with the rms energy spread of 9.8% in the cylindrical simulations.
4. The acceleration of positrons from initial 1 GeV to 126.8 GeV with a charge of ~10 pC over a distance of 1 m. The energy spread of accelerated positrons is 2.2%.

Thanks for your attention！