中国科学院高能物理研究所
Institute of High Energy Physics, Chinese Academy of Sciences

基于等离子体尾场加速的新型加速原理研究

——进展汇报及经费使用说明

李大章 加速器中心 物理组
on behalf of THU-IHEP AAC group

主要内容

- 课题目标及任务
- 课题设立以来的主要进展
- 经费使用情况
- 未来计划及预算

课题情况总体介绍

- 课题成立时间：2018年底；总经费：800万（科学家工作室）+300万（所创新基金）

- 总体目标：
  - ✓ 利用3-5年时间，全面开展CEPC Plasma Injector（出口能量45GeV，与增能环相连）的可行性研究，给出其是否可行的明确结论。如可行，给出尽可能详细的技术设计报告。

- 拟解决的关键问题：

✓ 大电量 shaped bunch 的产生	已完成初步设计和模拟，在做进一步优化
✓ 米级等离子体通道的产生及十米级等离子体通道的预研	米级等离子体通道已经实验验证
✓ 传统加速器的设计及与等离子体加速器的接口设计	已完成一轮Start-to-end模拟
✓ 电子的高变压比等离子体尾场加速及实验验证	dechirper实验已成功，上海实验待机中
✓ 正电子的等离子体尾场加速	一种新方法已被PRL接收，editor suggestion
✓ 用于正、负电子加速的等离子体尾场结构测量	前期实验有结果，上海实验待机中

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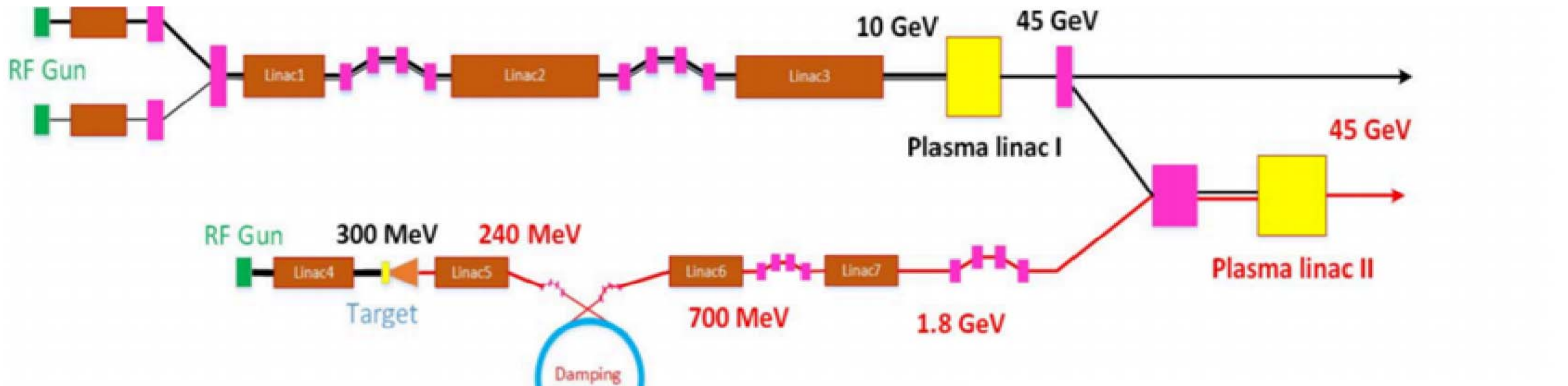
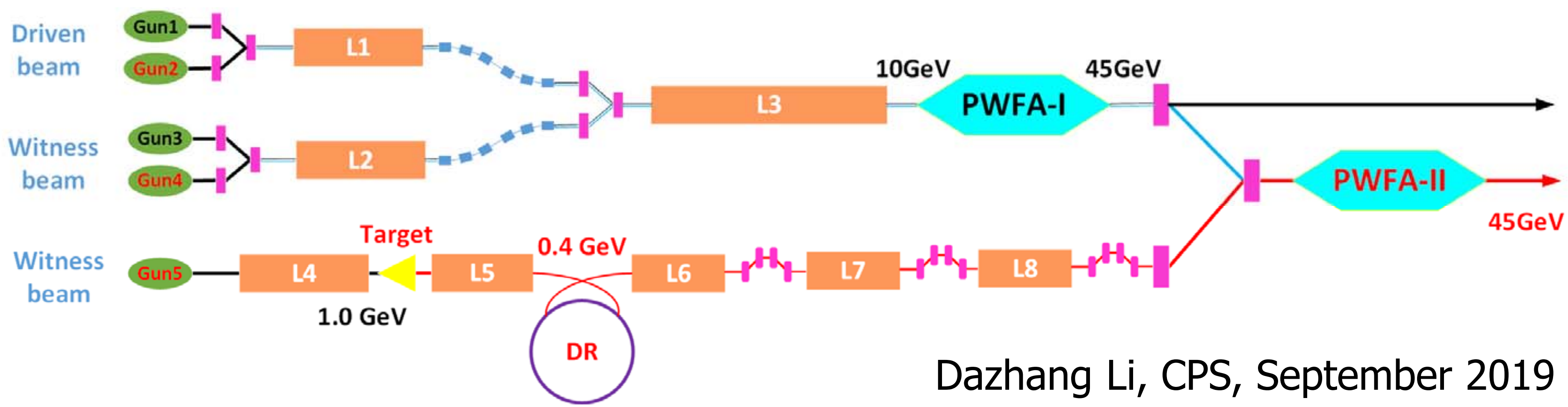
主要进展综述

- CEPC等离子体注入器相关的数值模拟研究
  - ✓ 等离子体尾场电子高变压比加速的模拟研究及误差分析（10GeV→45.5GeV，TR~4）
  - ✓ 高变压比尾场加速中的Hosing不稳定性对束流品质的影响及解决方法
  - ✓ 中变压比（10GeV-25GeV，TR≥1）尾场加速的数值模拟研究及误差分析
  - ✓ 等离子体尾场加速中高效正电子加速方案的探索
  - ✓ Start-to-end模拟
- CEPC等离子体注入器所需正、负电子源及直线加速器研究
  - ✓ 电子枪的选型及初步设计
  - ✓ 主直线加速器的优化
  - ✓ 正电子束线的设计与优化
  - ✓ 等离子体尾场加速专用TF装置的讨论
- CEPC等离子体注入器相关的实验研究
  - ✓ 清华Dechirper实验及米级中空等离子体通道的形成
  - ✓ 上海X-FEL装置的实验准备
  - ✓ 清华团队的其它相关实验进展
- 其它相关研究
  - ✓ 辐射阻尼在高能等离子体加速器中的影响
  - ✓ 双束PWFA实验中的最优参数选择与拟合方程
  - ✓ （激光）等离子体加速中的可控注入模拟研究
  - ✓ RF anomalous skin effect and CEPC RF photo-injector

总体进展：CPI概念设计 V1.0→V2.0

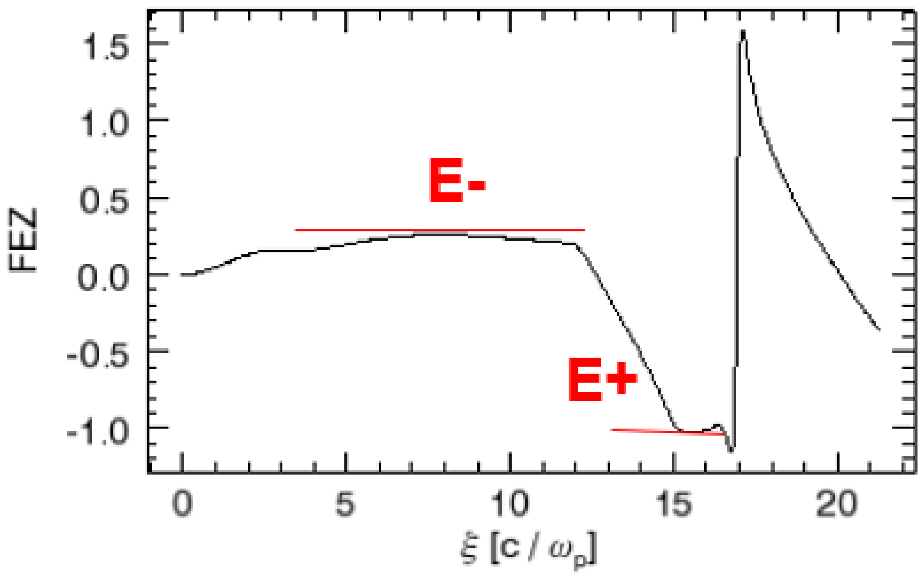


Jianfei Hua, AAC, August 2018



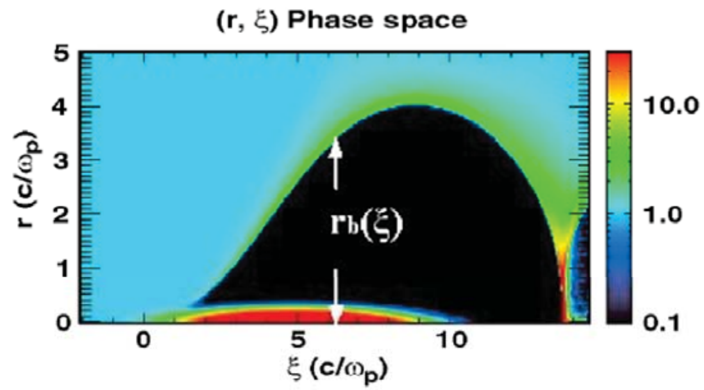
Dazhang Li, CPS, September 2019

等离子体尾场加速中的变压比



Nonlinear(Bubble) regime: nb/np>>1 or $\Lambda = n_b/n_p k_p^2 \sigma_r^2 > 1$

HIGH TRANSFORMER RATIO



The equation of boundary: $r_b \frac{d^2 r_b}{d\xi^2} + 2\left[\frac{d r_b}{d\xi}\right]^2 + 1 = \frac{4\lambda(\xi)}{r_b^2}$

$$\psi(r_\perp, \xi) \approx \frac{r_b^2(\xi)}{4} - \frac{r^2}{4}$$

$$E_z = \frac{\partial}{\partial \xi}\psi(r_\perp, \xi) \simeq \frac{1}{2} r_b \frac{d r_b}{d\xi} \quad E_\perp = E_r - B_\theta = \frac{r}{2}$$

Lu W , Huang C , Zhou M , et al, PRL(2006)

$$TR = E^+/E^-$$

$$TR = \frac{\bar{\gamma}_{trailer} - \gamma_{trailer\_initial}}{\bar{\gamma}_{driver} - \gamma_{driver\_initial}}$$

$$\eta = \frac{\sum_{i=1}^{n}{}_{E_i > E_t} (E_i - E_{trailer}) q_i}{\sum_{j=1}^{n}{}_{E_d > E_j} (E_{driver} - E_j) q_j}$$

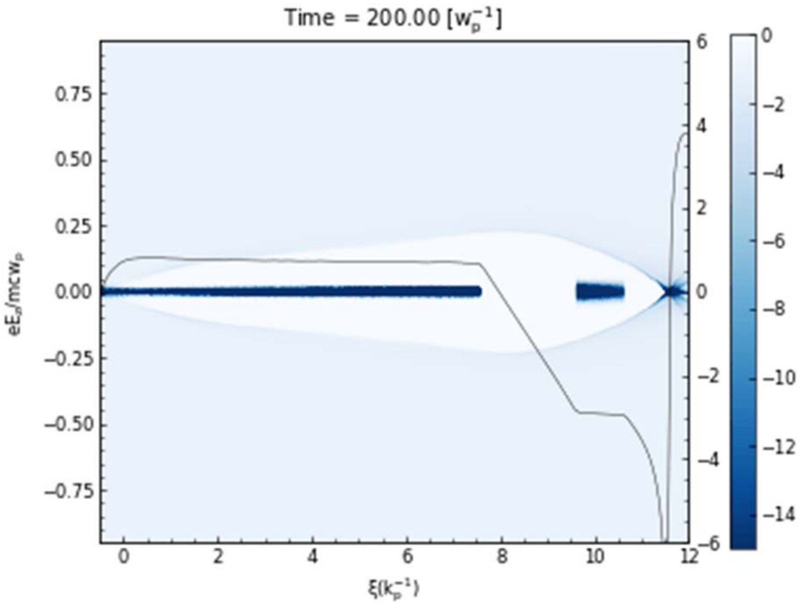
HTR mode, R ≥ (45.5-10)/10=3.55

Normal TR mode, R ≥ (20-10)/10=1

进展1.1 高变压比加速方案（理想情况）

beam	Driver	Trailer
plasma density n_p $(\times 10^{16} cm^{-3})$	0.50334	
Driver energy E (GeV)	10	10
Normalized emittance $\epsilon_n (mm\ mrad)$	50→20	100
Length (um)	600	77
(matched) Spot size(um)	20→3.87	20→8.65
Charge (nC)	5.8	1→0.84
Energy spread δ_E $(\%)$	0	0
Beam distance (um)	149	

Accelerating distance (m)	10.65
Driver energy $E(GeV)$	1.30
Trailer energy $E(GeV)$	45.5
Normalized emittance $\epsilon_n (mm\ mrad)$	98.44
Charge(nc)	0.84 (0.78)
Energy spread $\delta_E (\%)$	0.56
TR	~ 4
Efficiency (%) (driver → trailer)	59.1



- **10 GeV → 45.5 GeV e- acc. (on paper) work**
- **Much smaller $\sigma_{x,y}$ → Increase Linac difficulty**
- **Trailer's charge close to minimum request**
- **Assuming fully symmetric drive beam!**

Simulation performed by Dr. X. N. Wang and Prof. W. M. An (2020)

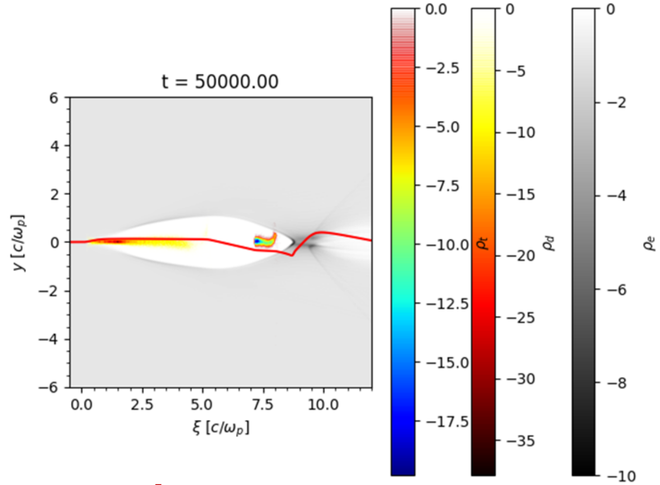
进展1.1 高变压比方案的误差分析

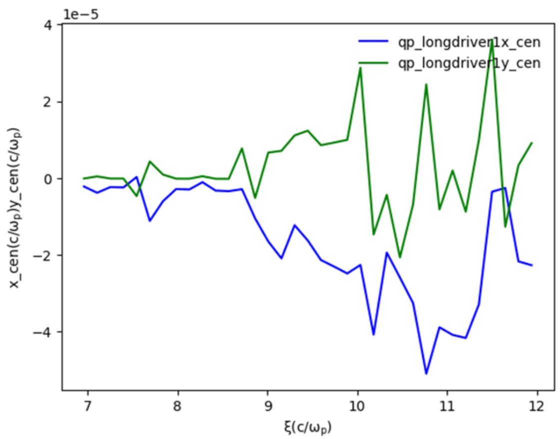
Slice jitter			
Slice jitter	Transverse position	Driver	±0.025nm
		Trailer	±3.7um
	Transverse velocity	Driver	<0.1nrad
		Trailer	<5urad

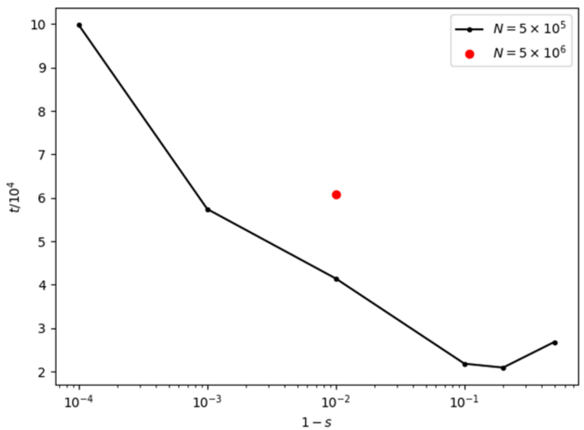
…mmetry, even let $<x_d> = 0$, the … example, adding only **0.025nm** … Actually, the resolution of the … d noise. **Is it physical or not?**

We did different studies and found that:

- **Increase particle number → hosing improved**
- **Increase the jitter (noise) to dx level or larger → hosing became more serious**
- **Partial particles asymmetry → hosing improved**







5×10^5 particles 99.99% symmetry $\sigma_z \sim 5$ lose 50% particles at 100000 ω_p^{-1}

Slide from Dr. X. N. Wang and Prof. W. M. An (2020); Dr. M. Zeng (2021)

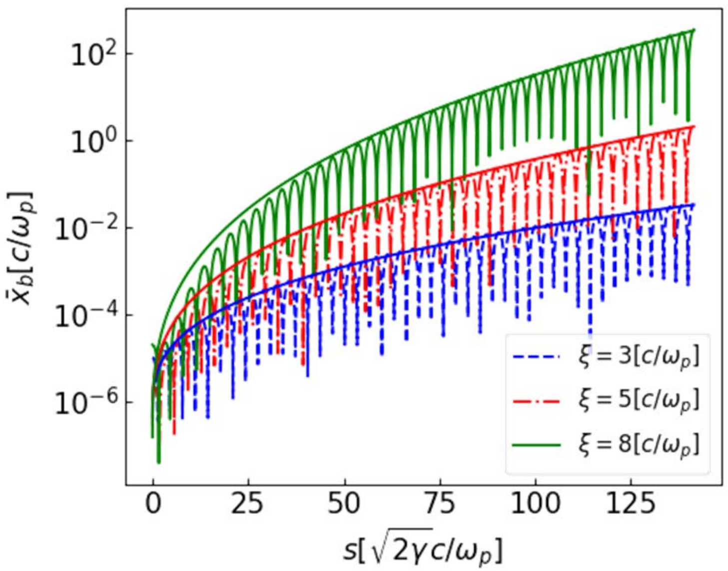
进展1.2 不稳定性来源及解决方法

- A straightforward way to calculate the asymptotic solution.
  - For the most basic equations

$$\frac{\partial^2 x_b}{\partial s^2} + x_b = k_\beta^2 x_c$$

$$\partial_\xi^2 \partial_s \bar{x}_b = \frac{\omega_0^2 k_\beta^2}{2ik_\beta}\bar{x}_b$$

$$\left[\gamma_0^3 n^2 m (k_\beta s)^{3m-1}(\omega_0\xi)^{3n-2}\omega_0^2 k_\beta + \frac{i\omega_0^2 k_\beta^2}{2k_\beta}\right]\bar{x}_b = 0$$



- We can obtain:

$$m = \frac{1}{3}, n = \frac{2}{3}$$

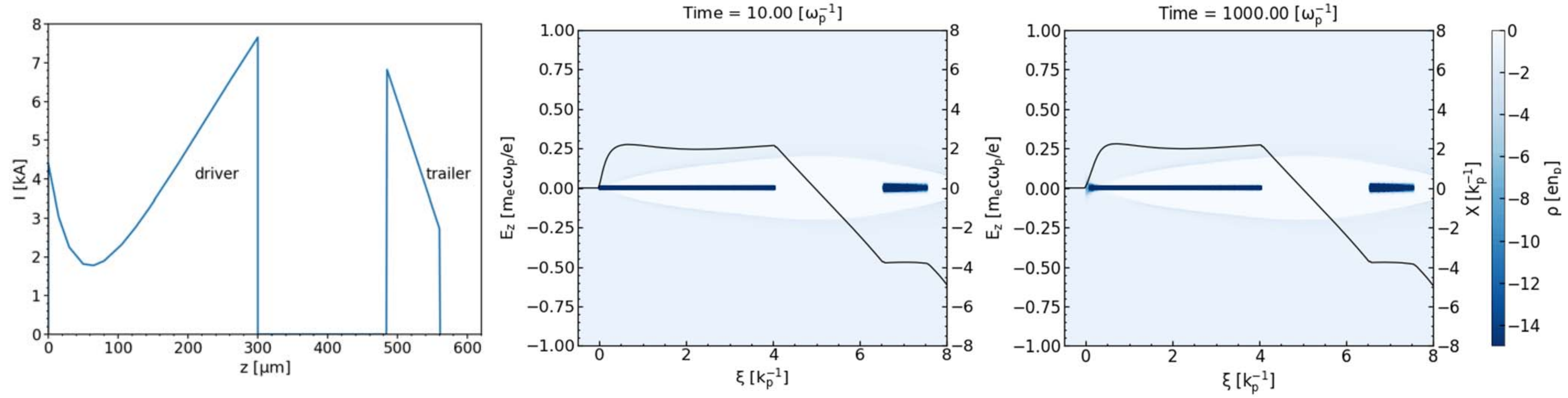
$$\gamma_0 = \frac{3}{2}(-i)^{1/3} = \frac{3}{2}\left(\frac{\sqrt{3}}{2} - \frac{i}{2}\right)$$

- $$\boldsymbol{x_b(s,\xi) = A_b e^{\frac{3}{2}\left(\frac{\sqrt{3}}{2}-\frac{i}{2}\right)(k_\beta s)^{1/3}(\omega_0\xi)^{2/3}} e^{ik_\beta s}}$$

It has the same exponential term with former researches, eg. A. A. Geraci and D. H. Whittum, Physics of Plasmas **7**, 3431 (2000)

C. Huang, W. Lu et al., PRL **99,** 255001 (2007)

进展1.3 中变压比方案（理想状态）



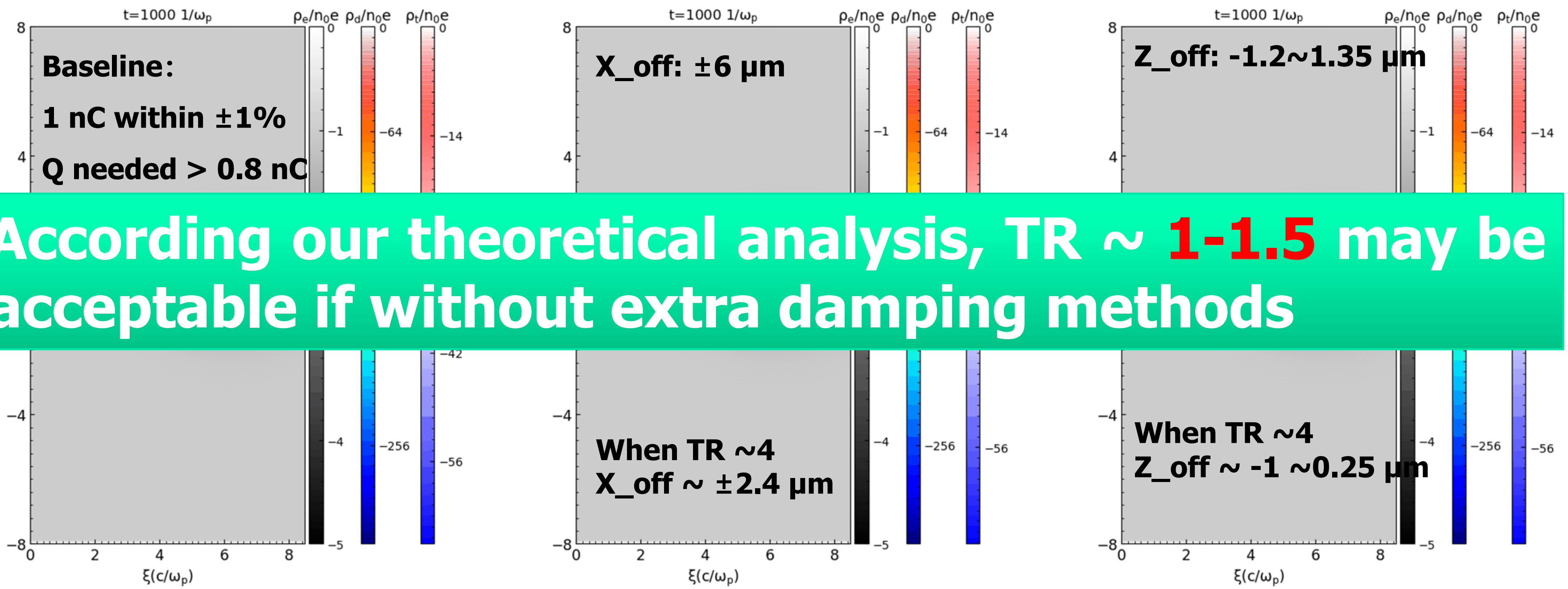
beam	Driver	Trailer
plasma density $n_p(\times 10^{16} cm^{-3})$	0.50334	
Driver energy $E(GeV)$	10	10
Normalized emittance $\epsilon_n(mm\ mrad)$	20	100
Length(um)	300	77
(matched)Spot size(um)	3.87	8.65
Charge(nC)	5.8→4	0.84→1.24
Energy spread $\delta_E(\%)$	0	0
Beam distance(um)	149→184	

	V1.0 HTR	V2.0 NTR
Accelerating distance (m)	10.7	4.8
Trailer energy $E(GeV)$	45.5	25
Normalized emittance $\epsilon_n(mm\ mrad)$	98.36	100
Charge(nC)	0.84	1.21
Energy spread $\delta_E(\%)$	0.40	0.40
TR	~ 4	~ 1.6
Efficiency(%) (driver -> trailer)	60.0	54.0

Slide from Dr. X. N. Wang, Dr. S. Y. Zhou and Prof. W. M. An (2021)

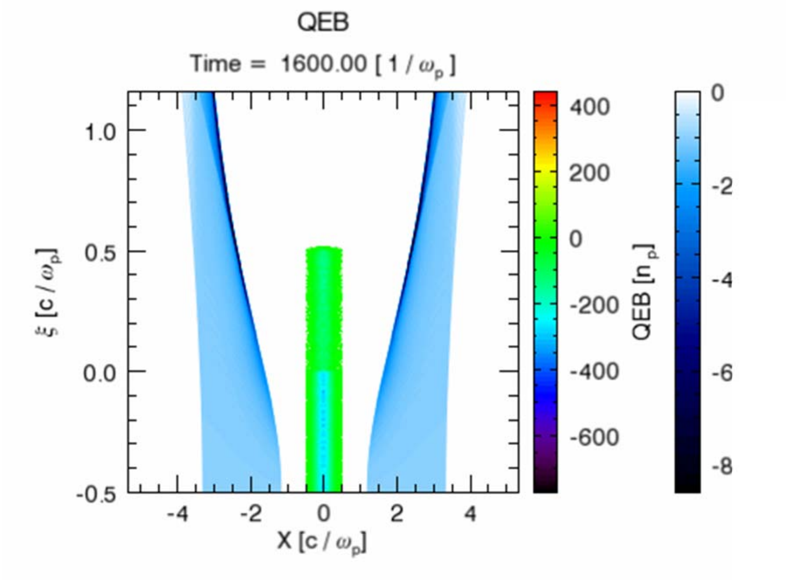
进展1.3 中变压比方案的误差容忍度

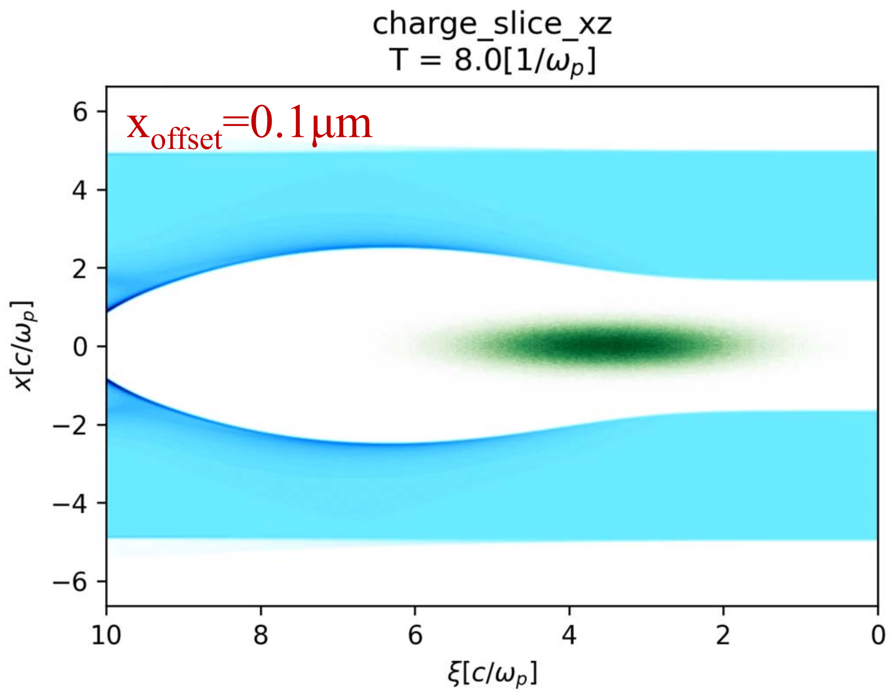
Asymmetry Ratio	Energy	Emittance (mm·mrad)	Bunch charge (0.2%)	Bunch charge (2%)	rms Energy spread
0	25.02 GeV	100 / 100	0.45 nC	1.36 nC	0.4%
0.1%	24.97 GeV	111 / 108	0.36 nC	1.36 nC	0.4%
1%	24.93 GeV	174 / 163	0.28 nC	1.36 nC	0.44%
2.5%	24.89 GeV	431 / 294	0.24 nC	1.33 nC	0.62%
10%	25.45 GeV	1057 / 1659	0.03 nC	0.28 nC	2.79%
2.5% (baseline)	26.25 GeV	645 / 496	1 nC (26.25 ±1%), TR ~ 1.76, η~52%		0.86%



According our theoretical analysis, TR ~ 1-1.5 may be acceptable if without extra damping methods

进展1.4 PWFA中高效正电子加速方案探索

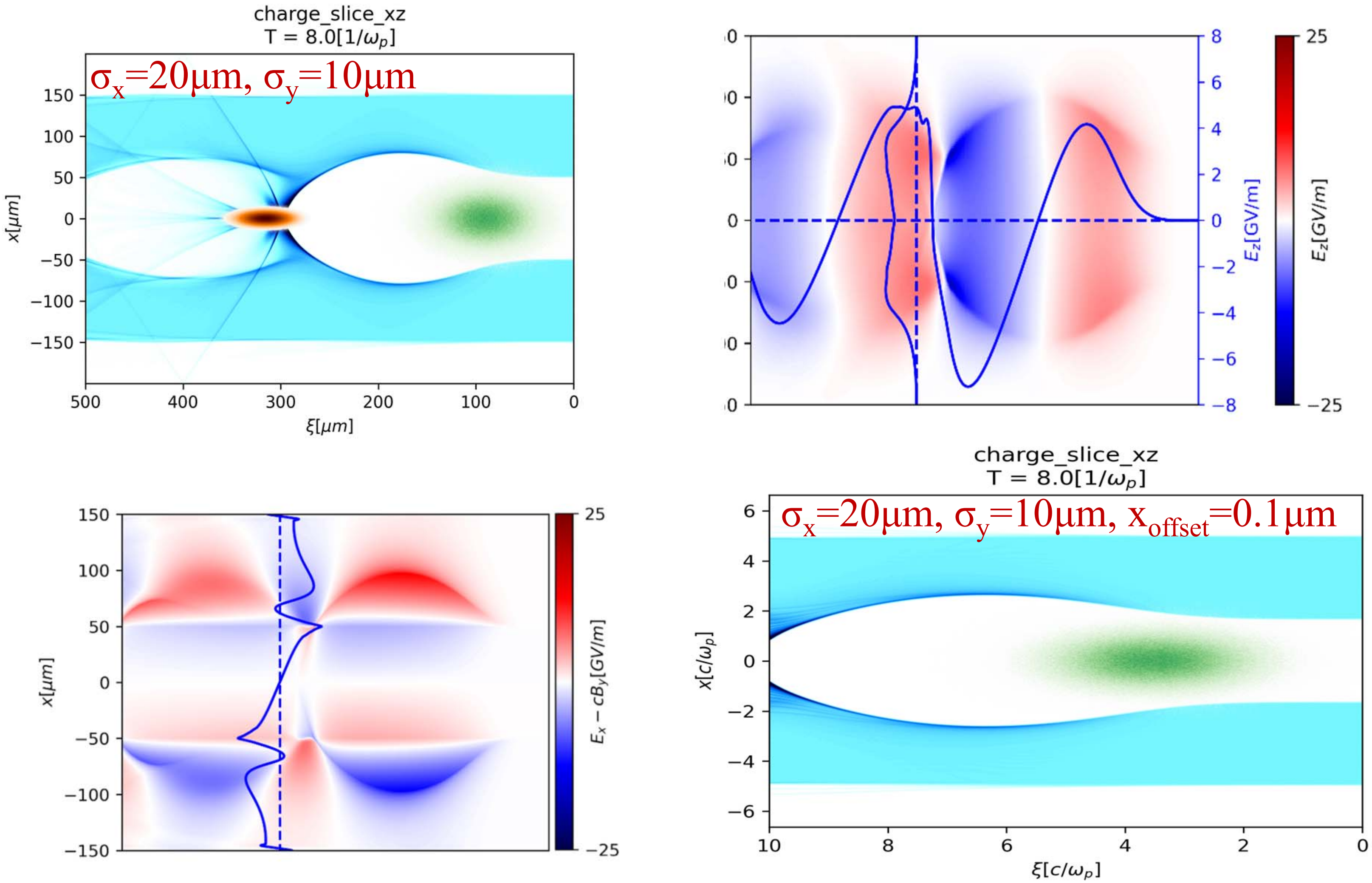




- **High efficiency 60%**
- **Low energy spread ~0.5%**
- **Small emittance growth**
- **Need e- driver, e+ trailer and plasma channel coaxial, not very practical**

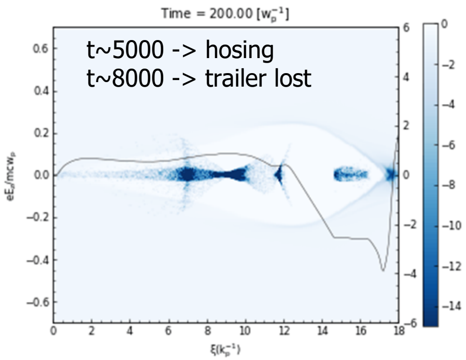
Simulation performed by THU team in 2018, based on the hollow channel idea *[S. Gessner et al., Nat. Commun. 7, 11785 (2016)]*

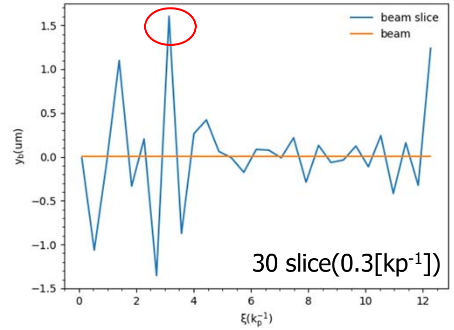
进展1.4 PWFA中高效正电子加速方案探索



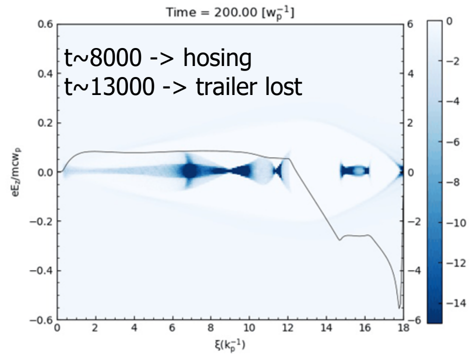
S. Y. Zhou, W. Lu, et al., Accepted by PRL, editor suggestion

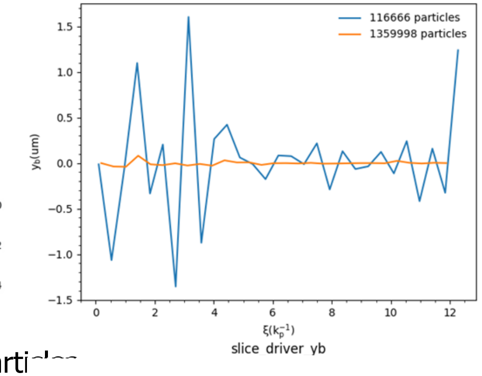
进展1.5 Start-to-end数值模拟



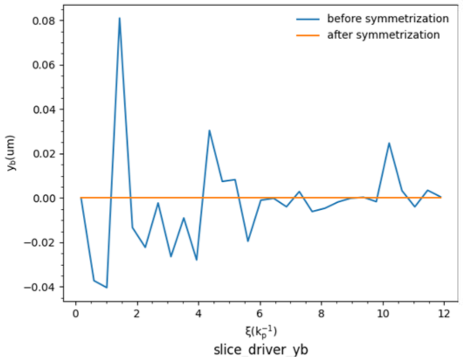


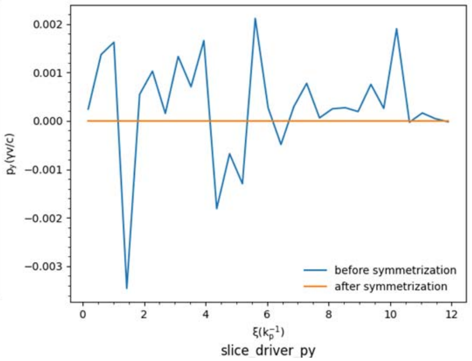
Driver initial beam centroid



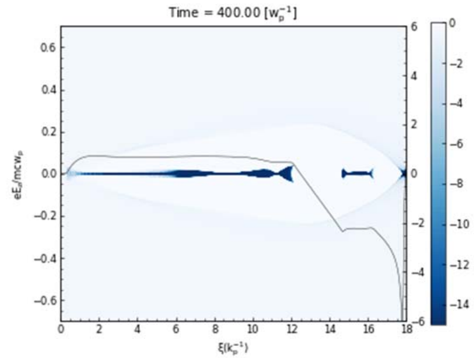


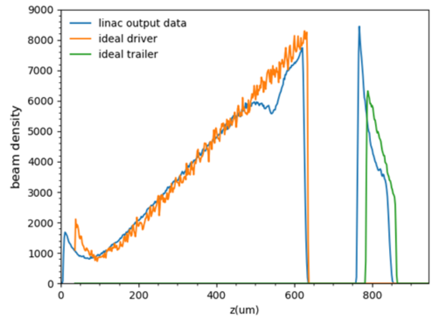
0.11m particles → 1.36m parti...

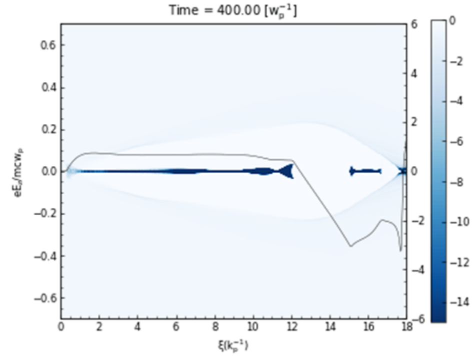


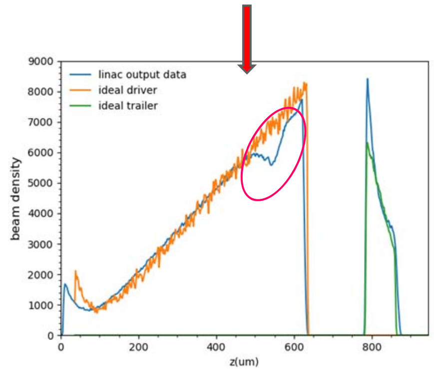


beam initial$[x, y, px, py]$~ [0,0,0,0]



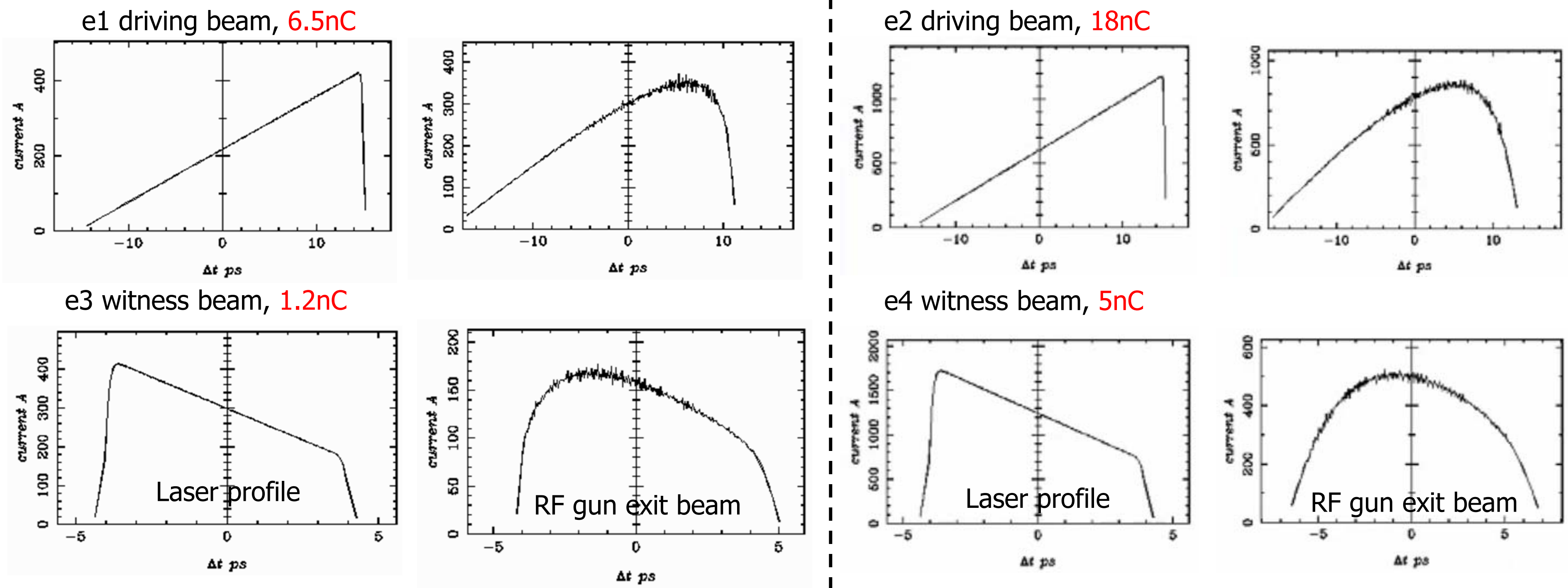






	Beam symmetrization	Change beam distance	Design
Δz(um)	126.7	149	149
$Et(GeV)$	40.6	42.80	45.5
Qt(nC)	0.9	0.7909	0.84

进展2.1 大电量密度调制的电子选型与设计



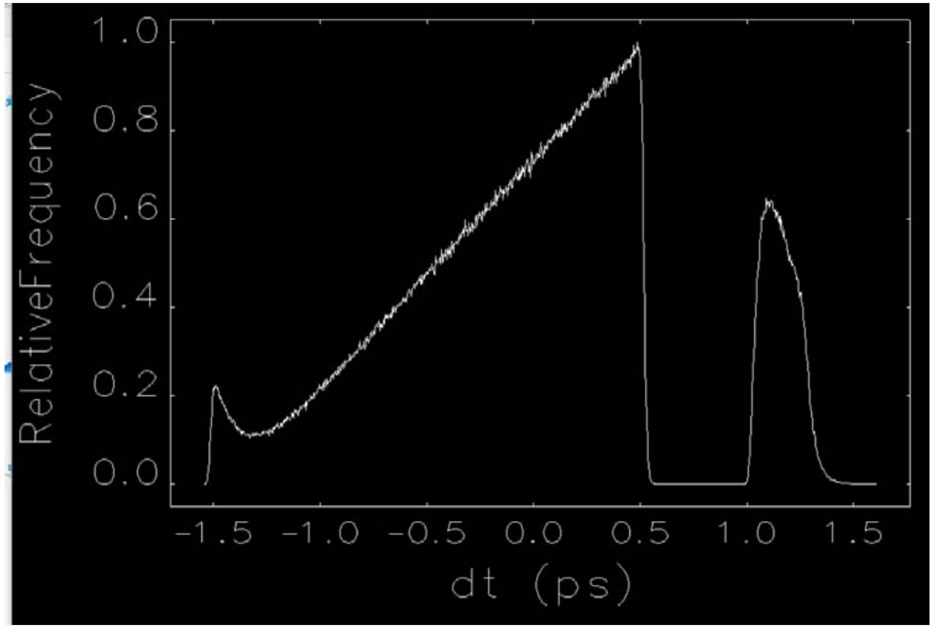
ASTRA Simulations for Electron Gun 1-4: L-band + Laser shaping

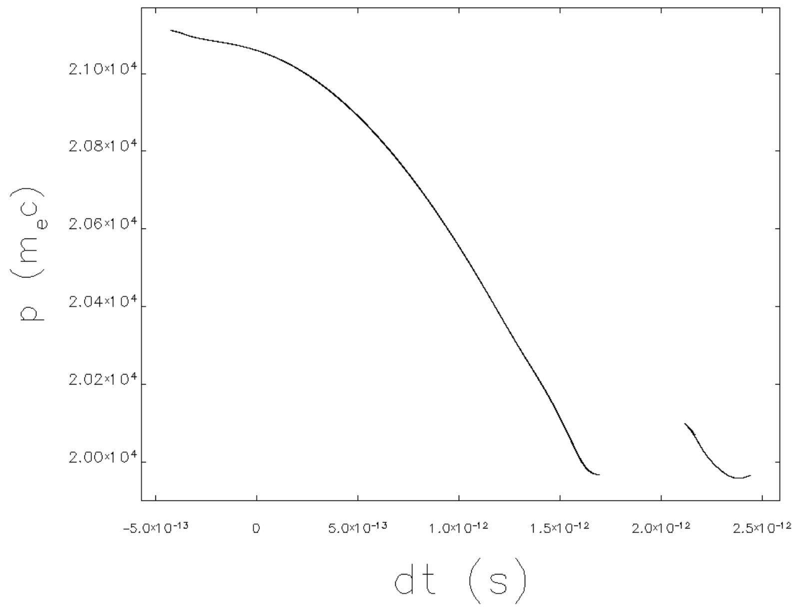
- **Preliminary beam dynamics simulations have achieved the expected longitudinal beam shapes. Further optimizations are needed.**
- **Laser shaping technique and beam line optics tuning for real condition (further bunch length compression in main linac) have to be investigated.**
- **Experiments to benchmark the beam dynamics study must to be done to verify the simulation reliability on large bunch charge case.**

Slides from Dr. Shu Guan

进展2.2 主直线加速器的设计与优化

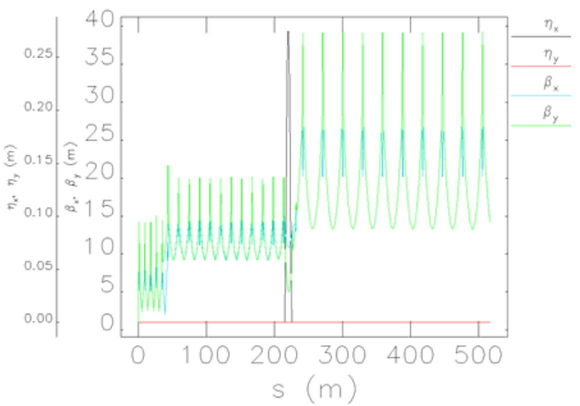
- Main Linac (Scheme-I)
  - ✓ If RF gun can provide electron beam with required shape, the main linac just accelerate beam to 10GeV.
  - ✓ Acceleration:
    - The longitudinal shape could be almost maintained
    - Short-range longitudinal wakefield + short bunch length + high bunch charge
      - Energy spread: 1.8% → Difficult design for FFS

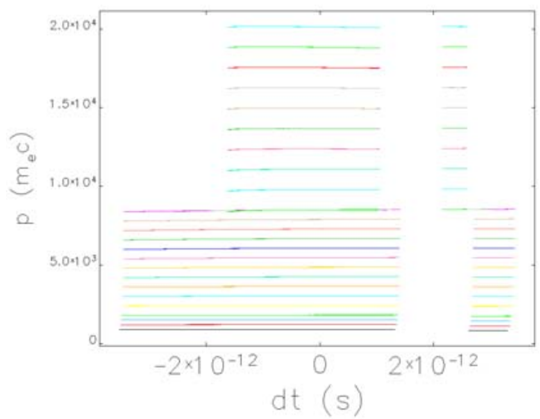


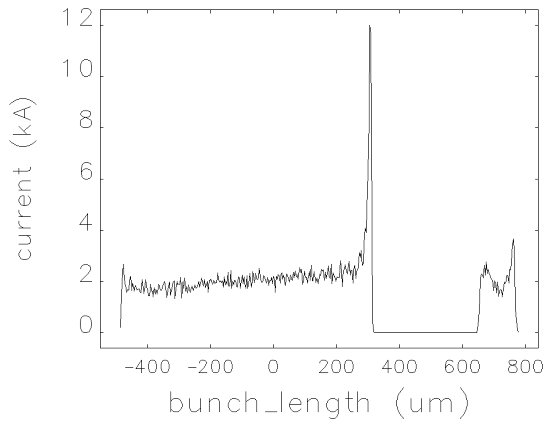


Slides from Dr. Meng Cai

- Main Linac (Scheme-II)
  - ✓ In order to decrease the energy spread and more flexible and compatible with other beam shaping scheme, one bunch compressor is introduced
    - Long bunch length beam + bunch compressor +short bunch length beam acceleration
    - High accelerating gradient s-band accelerating structure: 27MV/m
    - Energy spread: 0.275%
  - ✓ Longitudinal deformation, need more optimization

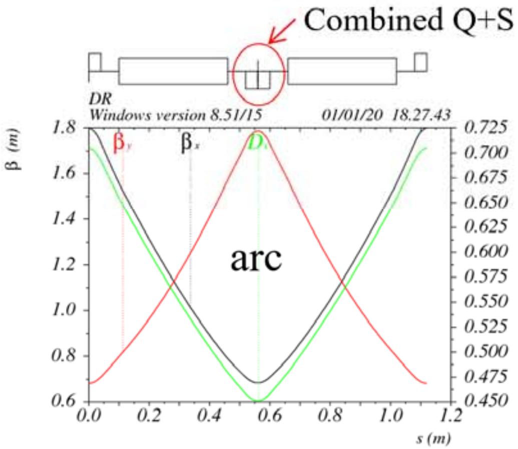


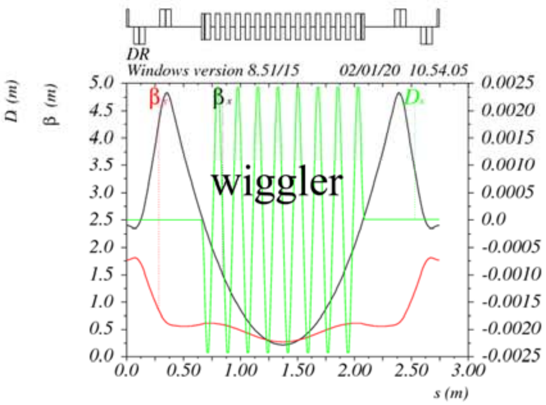


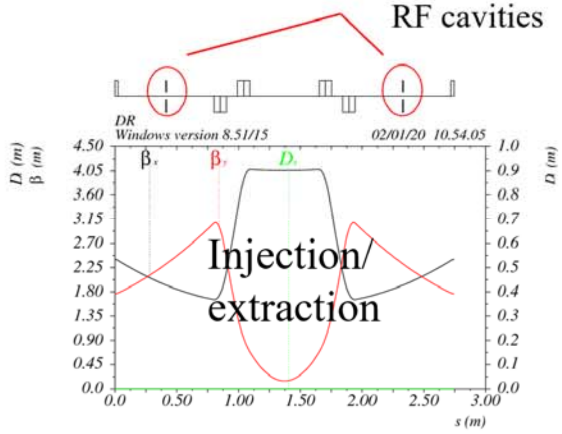


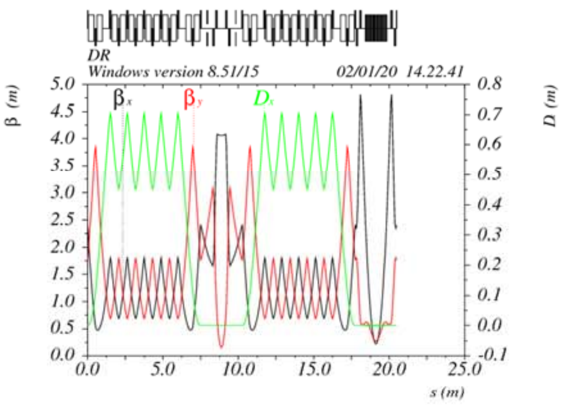
Slides from Dr. Meng Cai

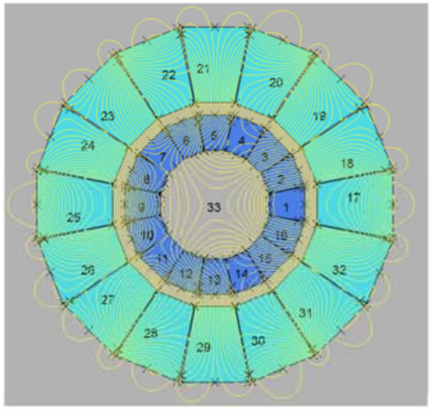
进展2.3 正电子束线设计与优化

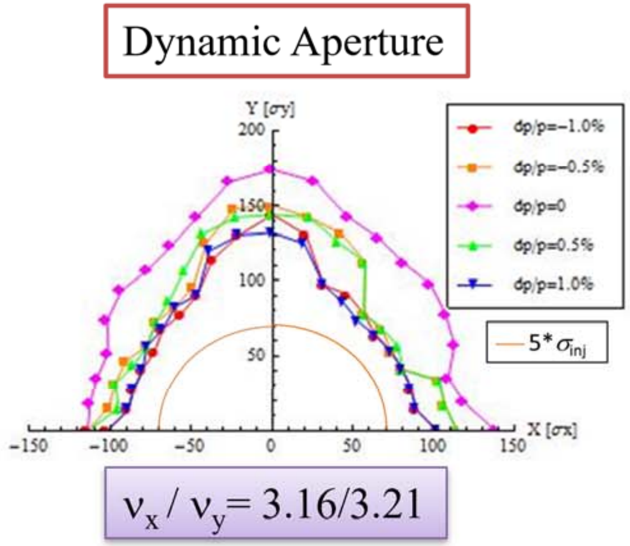












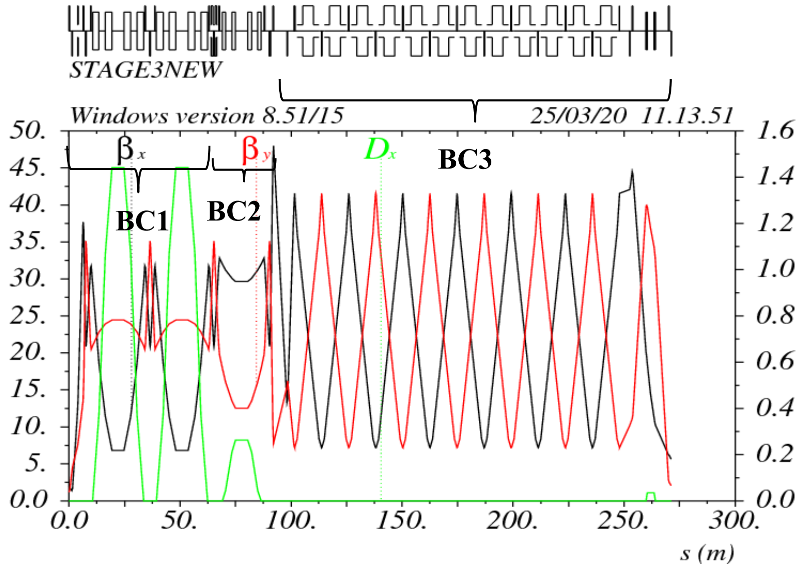
- Combined quadrupole + sextupole (permanent magnet)
- Superconducting wiggler → shorter damping time & smaller equilibrium emittance

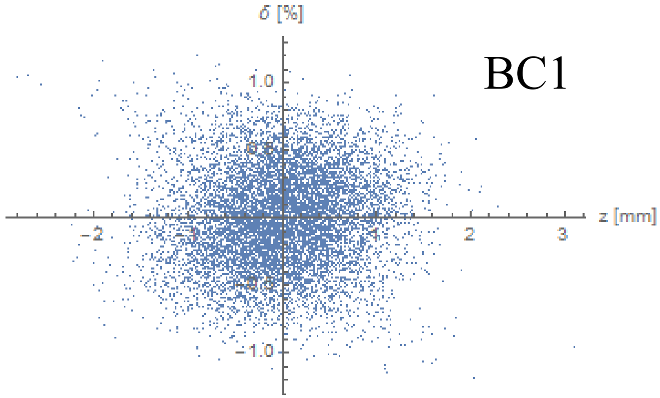
By Dr. Dou Wang and Cai Meng from IHEP (2020)

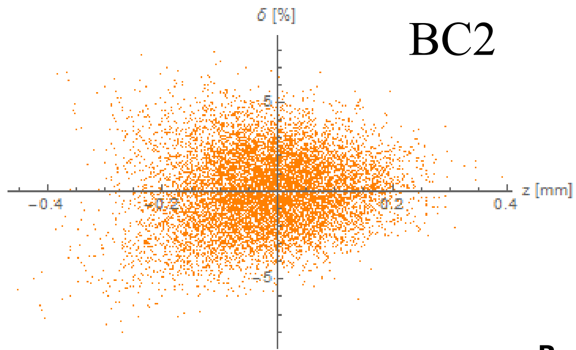
进展2.3 正电子束线设计与优化

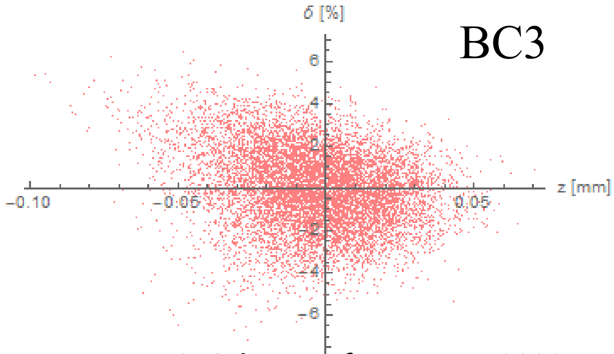
	BCI	BCII	BCIII
Initial energy (MeV)	400	400.1	405
δinj (%)	0.05	0.367	2.17
Initial σz (mm)	4.4	600	100
f_{RF} (GHz)	2.860	5.712	5.712
Voltage(GV)	0.0056	0.12	4.18
Gradient (MV/m)	20	40	40
L (m)	0.28	3	104
ϕ_{RF} (degree)	89	88	61.5
R_{56} (mm)	1200	27.6	5.5
Final energy(MeV)	400.1	405	2400
δext (%)	0.367	2.17	1.83
final σz (um)	600	100	20

- Energy: 400MeV → 2.4 GeV
- Bunch length: 4.4mm → 20um
- Energy spread: 0.054% → 1.8%



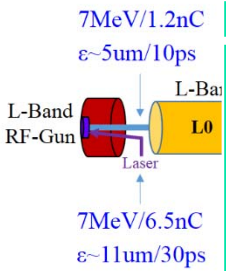


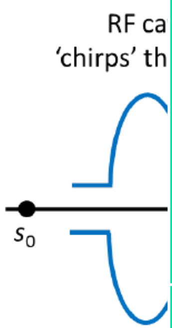




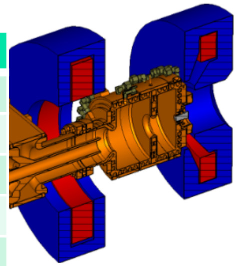
By Dr. Dou Wang & Cai Meng from IHEP (2020)

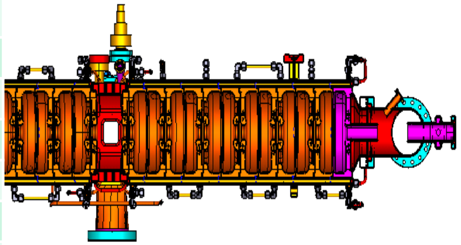
进展2.4 PWFA专用TF装置的构想

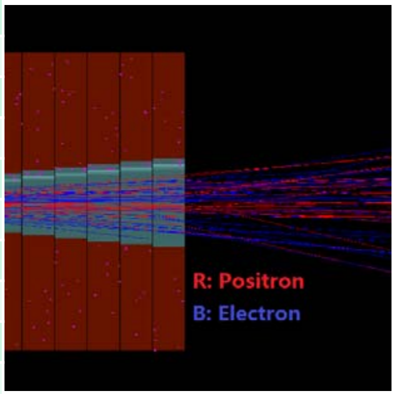




	参数	单位	参数要求	Baseline设计值
驱动电子束	能量	GeV	1	1
	束团电荷量	nC	6	6
	束团重复频率	Hz	1	5
	发射度（归一化）	μm-rad	≤30	≤25
	横向束斑尺寸	μm	40	35
	束团长度	ps	2	2
	能散（rms）	—	待定	1%待定
	脉冲流强	kA	3	3
被加速电子束	能量	GeV	1	1
	束团电荷量	nC	1	1
	束团重复频率	Hz	1	5
	发射度（归一化）	μm-rad	≤8	≤5
	横向束斑尺寸	μm	21	16
	束团长度	ps	0.7	0.7
	能散（rms）	—	待定	1%待定
	脉冲流强	kA	1.4	1.4
被加速正电子束	能量	MeV	200	200
	束团电荷量	nC	1.5	1.5
	束团重复频率	Hz	1	5
	发射度（归一化）	μm-rad	≤10	≤10
	横向束斑尺寸	μm	30*30	20*20
	束团长度	ps	0.7	0.6
	能散（rms）			
	峰值流强	kA	2	2.5

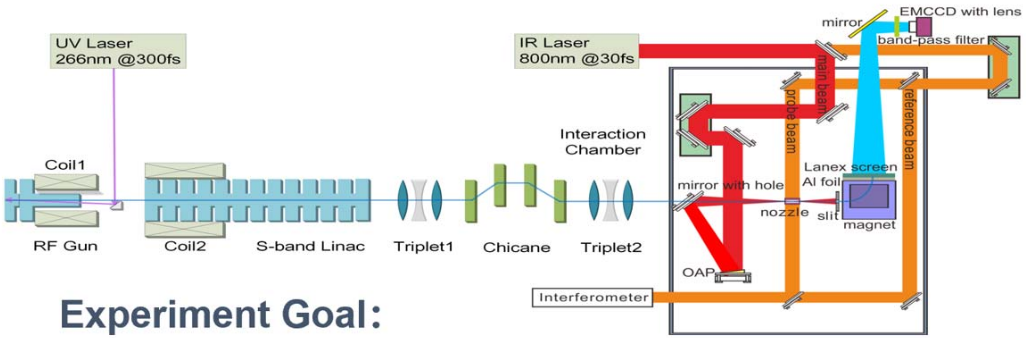






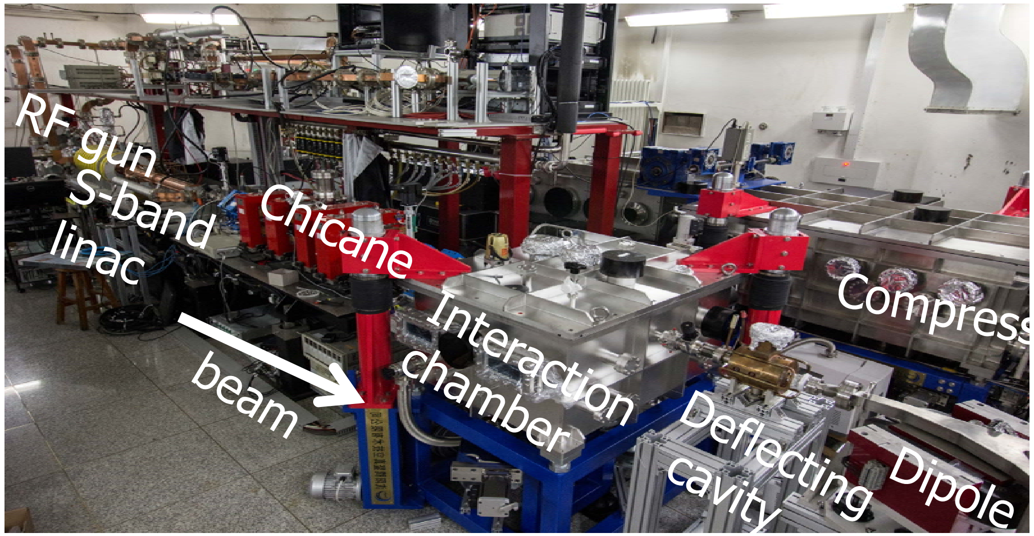
2021年8月-11月，李煜辉老师组织讨论，李小平、段哲、麻惠洲、王毅伟等10人共同编写TF装置设计草案

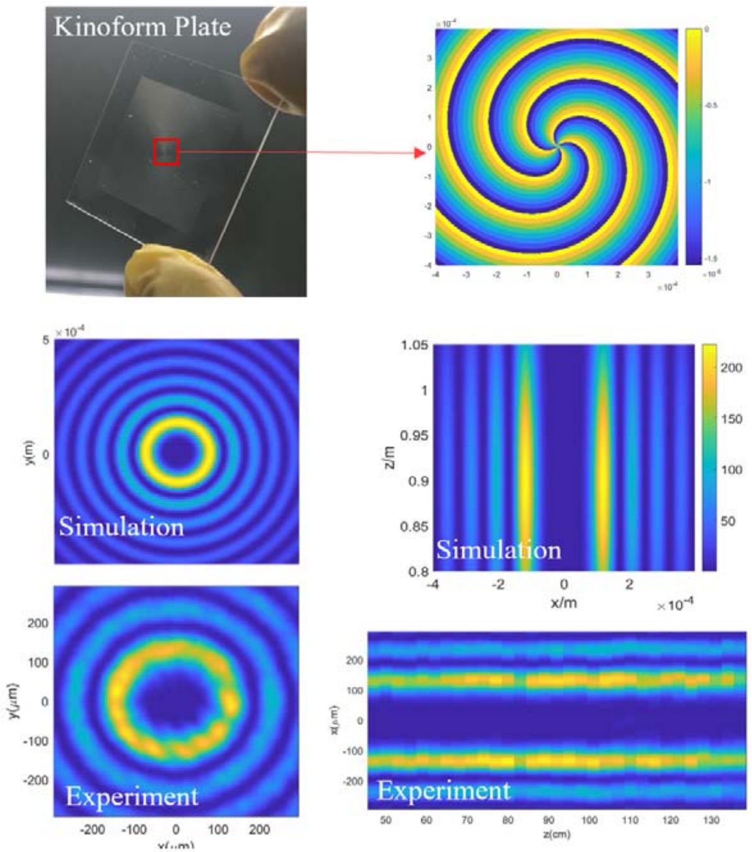
进展3.1 Plasma Dechirper实验@THU



Experiment Goal:

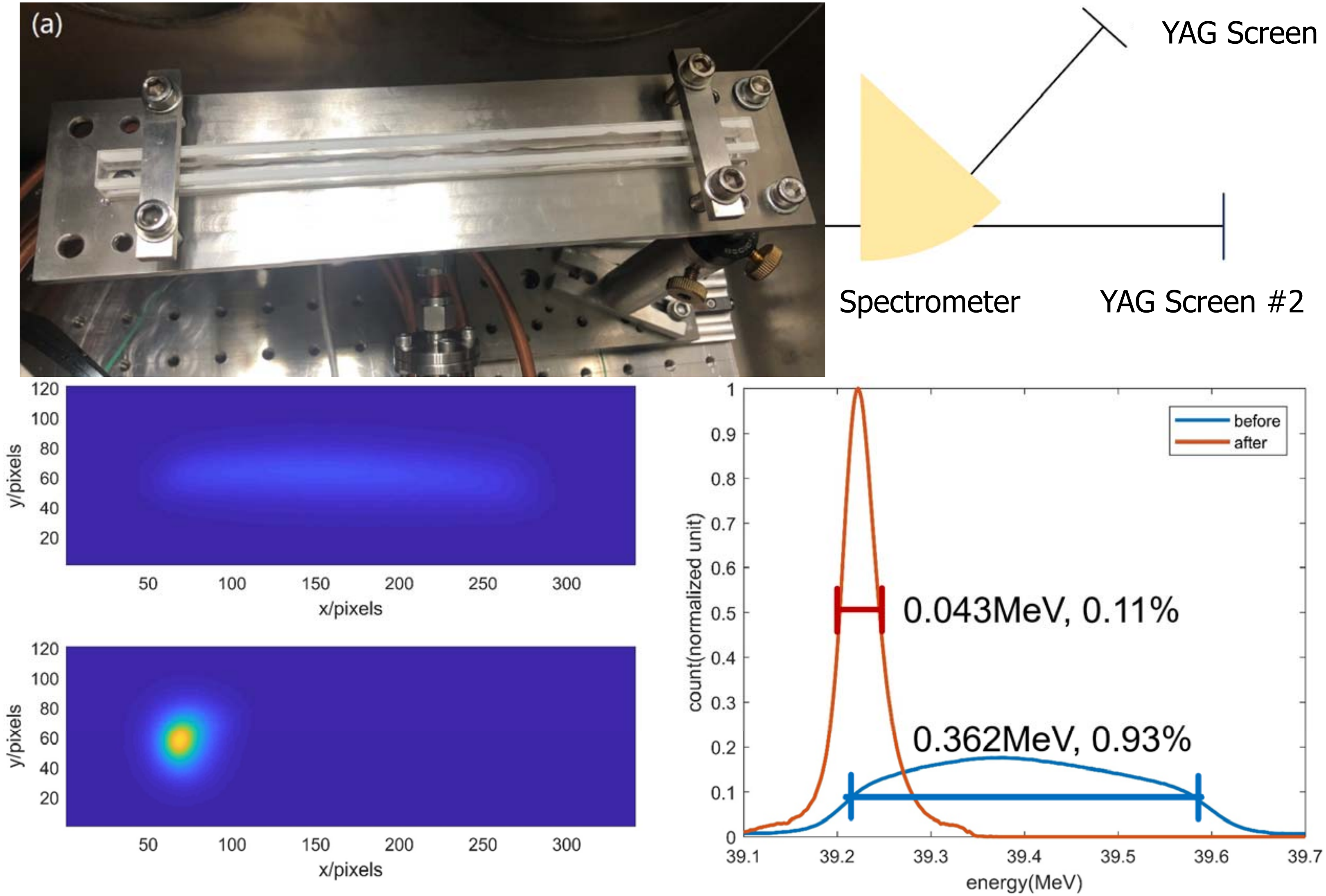
1. Decrease the energy spread from 1% to 0.1%
2. Study Hollow channel impact on beam quality





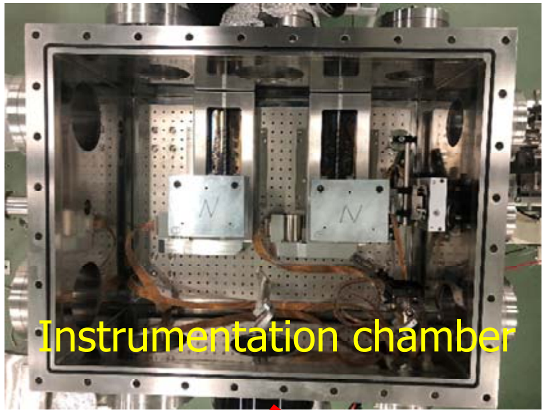
Slides from Dr. Shuang Liu (2020)

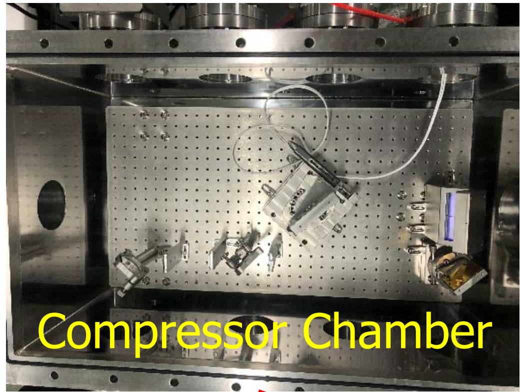
进展3.1 Plasma Dechirper实验@THU



Slides from Dr. Shuang Liu (2020)

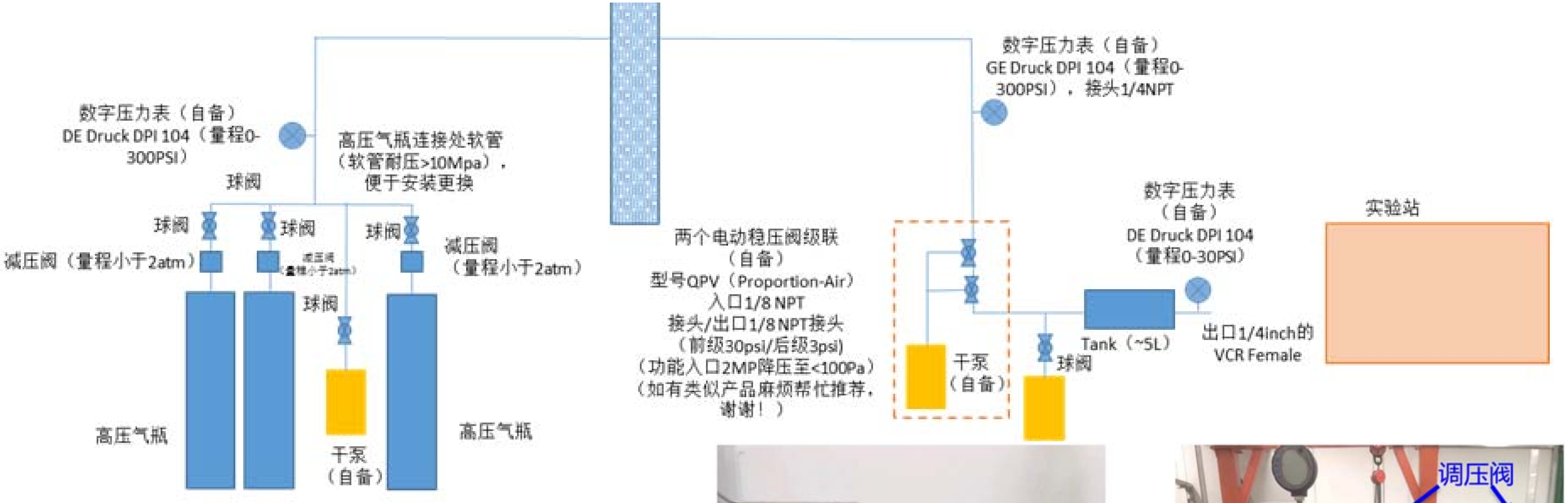
进展3.2 PWFA实验@SX-FEL





Slides from Dr. Bo Peng (2020)

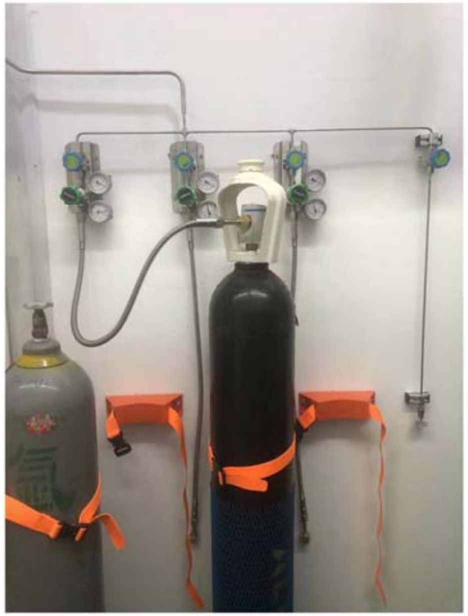
进展3.2 PWFA实验@SX-FEL



高压气瓶为混合气体（He：N2混合的摩尔比=90:10或者99:1）

Requirement:

200 ~ 10^5 pa (Negative pressure)



进展3.3 清华团队其它相关实验结果

nature physics

LETTERS

https://doi.org/10.1038/s41567-021-01202-6

Check for updates

High-throughput injection–acceleration of electron bunches from a linear accelerator to a laser wakefield accelerator

Yipeng Wu[1,2], Jianfei Hua[1]✉, Zheng Zhou[1], Jie Zhang[1], Shuang Liu[1], Bo Peng[1], Yu Fang[1], Xiaonan Ning[1], Zan Nie[2], Fei Li[2], Chaojie Zhang[2], Chih-Hao Pai[1], Yingchao Du[1]✉, Wei Lu[1]✉, Warren B. Mori[2] and Chan Joshi[2]

SCIENTIFIC REPORTS

OPEN

Capturing relativistic wakefield structures in plasmas using ultrashort high-energy electrons as a probe

Received: 03 May 2016
Accepted: 20 June 2016
Published: 11 July 2016

C. J. Zhang[1,2,4], J. F. Hua[1], X. L. Xu[3], F. Li[1], C.-H. Pai[1], Y. Wan[1], Y. P. Wu[1], Y. Q. Gu[2], W. B. Mori[3], C. Joshi[3] & W. Lu[1,4]

进展4.1 高能等离子体加速中的辐射阻尼问题

IOP Publishing New J. Phys. 23 (2021) 075008 https://doi.org/10.1088/1367-2630/ac12fa

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9 July 2021

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28 July 2021

PAPER

Radiation reaction of betatron oscillation in plasma wakefield accelerators

Ming Zeng[1,2,*] and Keita Seto[3,4]

[1] Institute of High Energy Physics, Chinese Academy of Sciences, 100049 Beijing, People's Republic of China
[2] University of Chinese Academy of Sciences, 100049 Beijing, People's Republic of China
[3] Extreme Light Infrastructure—Nuclear Physics (ELI-NP), 077125 Magurele, Romania
[4] Horia Hulubei National Institute for R & D in Physics and Nuclear Engineering (IFIN-HH), 077125 Magurele, Romania
[*] Author to whom any correspondence should be addressed.

E-mail: zengming@ihep.ac.cn

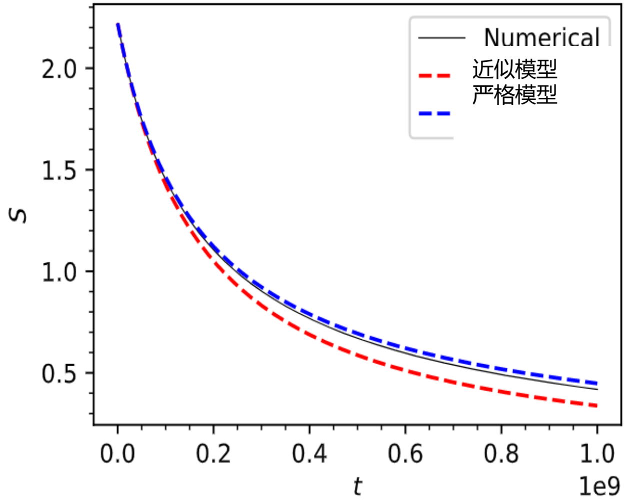
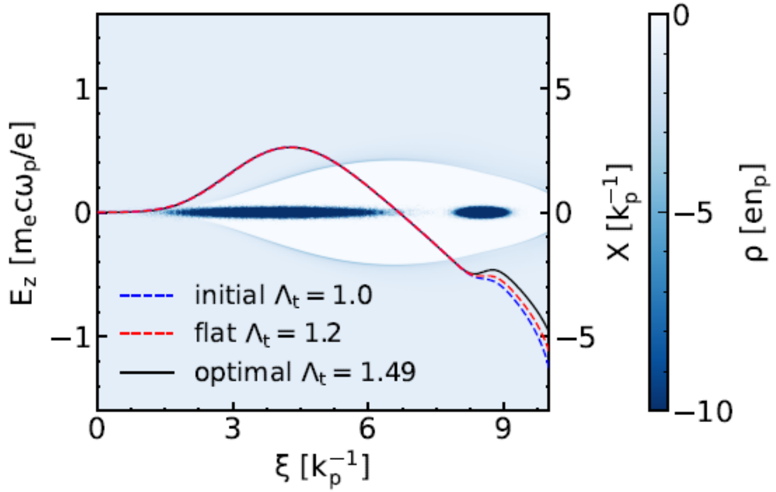


Table 1. Some examples of $\gamma_{0\max}$, L_S and $\chi_{\max}$ with varying n_p, S and γ_0.

Case No.	n_p (cm^{-3})	k_p (m^{-1})	S	$\gamma_{0\max}$	γ_0	L_S (m)	$\chi_{\max}$
1	10^{18}	1.88×10^5	2	5.4×10^6	1×10^5	563.2	1.9×10^{-4}
2					5×10^6	80.0	3.6×10^{-3}
3			8	2.1×10^6	1×10^5	140.8	3.9×10^{-4}
4					2×10^6	31.5	3.7×10^{-3}
5	10^{17}	5.95×10^4	2	1.2×10^7	1×10^5	5632	6.1×10^{-5}
6					1×10^7	563.2	1.9×10^{-3}
7			8	4.6×10^6	1×10^5	1408	1.2×10^{-4}
8					4×10^6	222.6	2.0×10^{-3}

- **1st detailed analysis on RR effects of an e-'s BO in a PWA**
- **Both classical and quantum conditions are considered**
- **Published on NJP (CAS, Q2 top)**
- **Can be ignored in CPI, even for full energy injection**

进展4.2 双束PWFA中最优参数的选取



- **Trailer's relative energy spread is related to $Q_d, Q_t, \sigma_{zd}, \sigma_{zt}, \sigma_{rd}, \sigma_{rt}, d_{dt}, n_p$**
- **Reduce the coefficients' # by introducing charge per unit length $\Lambda = n_b \sigma_r^2$**
- **Scan a large range to fix the fitting formula for $\Lambda_t = f(\Lambda_d, \sigma_{zd}, \sigma_{zt}, d_{dt})$**

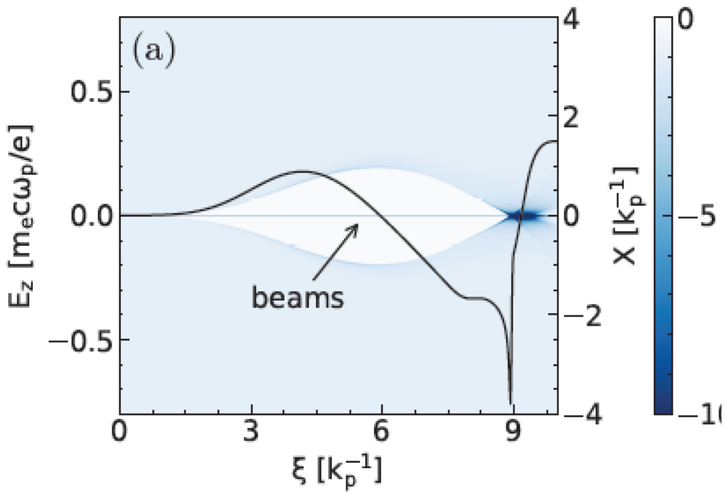


TABLE I. Parameters range obtained from automatic optimizations.

Parameters	Range
Λ_d	$[0.0885, 7.70]$
σ_{zd} $[k_p^{-1}]$	$[0.0952, 1.90]$
d_{dt} $[k_p^{-1}]$	$[1.60, 11.1]$ (the gloabal range)
σ_{zt} $[k_p^{-1}]$	$[0.0952, 0.857]$
Λ_t	$[0.0627, 3.14]$

进展4.2 双束PWFA中最优参数的选取

$$\Lambda_t = h_0 + h_1\Lambda_d + h_2\sigma_{zd} + h_3\sigma_{zt} + h_4 d_{dt} + h_5\Lambda_d^2 + h_6\Lambda_d\sigma_{zd} + h_7\Lambda_d\sigma_{zt} + h_8\Lambda_d d_{dt} + h_9\sigma_{zd}^2 + +h_{10}\sigma_{zd}\sigma_{zt} + h_{11}\sigma_{zd}d_{dt} + h_{12}\sigma_{zt}^2 + h_{13}\sigma_{zt}d_{dt} + h_{14}d_{dt}^2 + h_{15}\Lambda_d^3 + h_{16}\Lambda_d^2\sigma_{zd} + h_{17}\Lambda_d^2\sigma_{zt} + h_{18}\Lambda_d^2 d_{dt} + h_{19}\Lambda_d\sigma_{zd}^2 + h_{20}\Lambda_d\sigma_{zd}\sigma_{zt} + h_{21}\Lambda_d\sigma_{zd}d_{dt} + h_{22}\Lambda_d\sigma_{zt}^2 + h_{23}\Lambda_d\sigma_{zt}d_{dt} + h_{24}\Lambda_d d_{dt}^2 + h_{25}\sigma_{zd}^3 + h_{26}\sigma_{zd}^2\sigma_{zt} + h_{27}\sigma_{zd}^2 d_{dt} + h_{28}\sigma_{zd}\sigma_{zt}^2 + h_{29}\sigma_{zd}\sigma_{zt}d_{dt} + h_{30}\sigma_{zd}d_{dt}^2 + h_{31}\sigma_{zt}^3 + h_{32}\sigma_{zt}^2 d_{dt} + h_{33}\sigma_{zt}d_{dt}^2 + h_{34}d_{dt}^3, \quad (2)$$

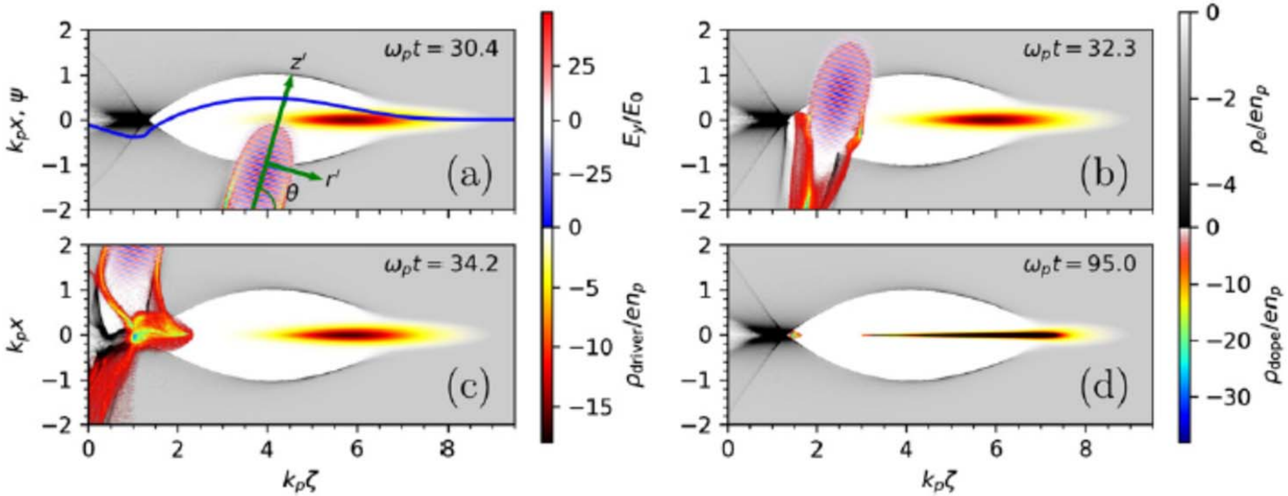
h_1=3.658×10^{-1}	h_2=9.119×10^{-1}	h_3=-1.083	h_4=3.062×10^{-1}	h_5=-3.754×10^{-2}
h_6=2.344	h_7=1.281×10^{-1}	h_8=-5.028×10^{-2}	h_9=-7.136×10^{-1}	h_{10}=-1.915×10^{-1}
h_{11}=-1.316×10^{-1}	h_{12}=-2.167	h_{13}=1.034	h_{14}=-7.607×10^{-2}	h_{15}=-2.391×10^{-3}
h_{16}=-7.570×10^{-2}	h_{17}=2.641×10^{-2}	h_{18}=1.160×10^{-2}	h_{19}=-8.626×10^{-1}	h_{20}=-2.424×10^{-1}
h_{21}=9.630×10^{-2}	h_{22}=3.874×10^{-1}	h_{23}=-7.137×10^{-2}	h_{24}=-3.061×10^{-3}	h_{25}=1.238×10^{-1}
h_{26}=3.752×10^{-2}	h_{27}=7.655×10^{-2}	h_{28}=5.197×10^{-1}	h_{29}=-2.585×10^{-2}	h_{30}=-6.071×10^{-3}
h_{31}=-2.866	h_{32}=1.231	h_{33}=-2.525×10^{-1}	h_{34}=6.674×10^{-3}	h_0=-5.014×10^{-1}

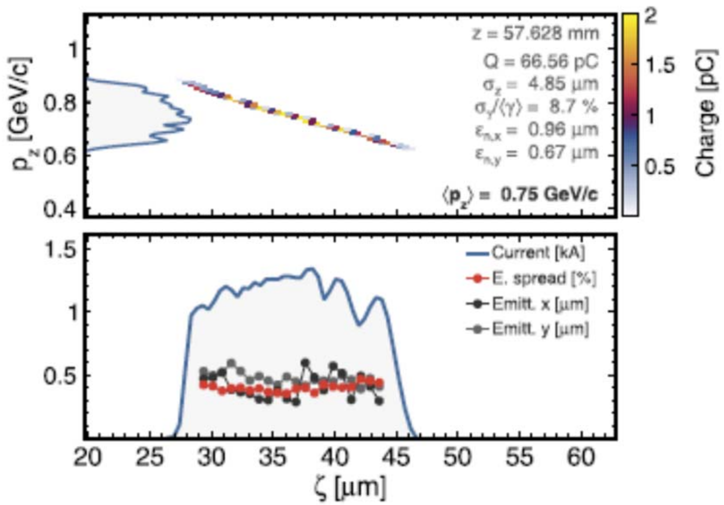
- By using the BFGS algorithm and QuickPIC to obtain a large amount of optimal cases
- By using polynomial regression to calculate all the coefficients
- Valid for 2-bunch, tri-Gaussian electron beams
- Submitted to PPCF (CAS Q2)

$$R = p_0 + p_1\Lambda_d + p_2\sigma_{zd} + p_3\sigma_{zt} + p_4 d_{dt} + p_5\Lambda_t + p_6\Lambda_d^2 + p_7\Lambda_d\sigma_{zd} + p_8\Lambda_d\sigma_{zt} + p_9\Lambda_d d_{dt} + p_{10}\Lambda_d\Lambda_t + p_{11}\sigma_{zd}^2 + p_{12}\sigma_{zd}\sigma_{zt} + p_{13}\sigma_{zd}d_{dt} + p_{14}\sigma_{zd}\Lambda_t + p_{15}\sigma_{zt}^2 + p_{16}\sigma_{zt}d_{dt} + p_{17}\sigma_{zt}\Lambda_t + p_{18}d_{dt}^2 + p_{19}d_{dt}\Lambda_t + p_{20}\Lambda_t^2, \quad (3)$$

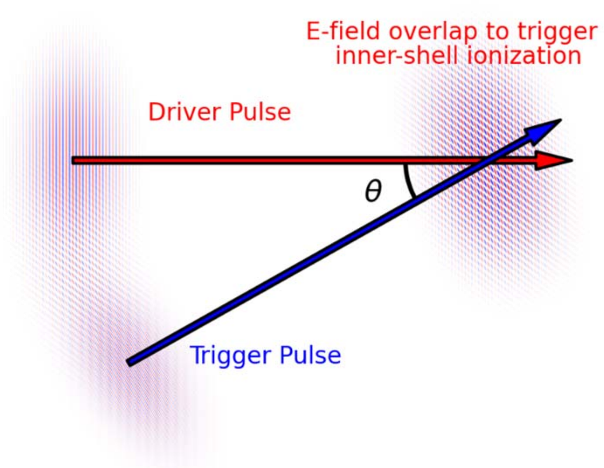
p_1=0.3199	p_2=0.3178	p_3=0.3084	p_4=0.7241	p_5=-0.8454	p_6=0.02719	p_7=0.4858
p_8=0.4140	p_9=-0.1070	p_{10}=-0.02761	p_{11}=-0.2779	p_{12}=-0.4929	p_{13}=0.2440	p_{14}=-0.3681
p_{15}=1.632	p_{16}=-0.6407	p_{17}=-0.01004	p_{18}=-0.01716	p_{19}=0.01430	p_{20}=0.1439	p_0=-1.453

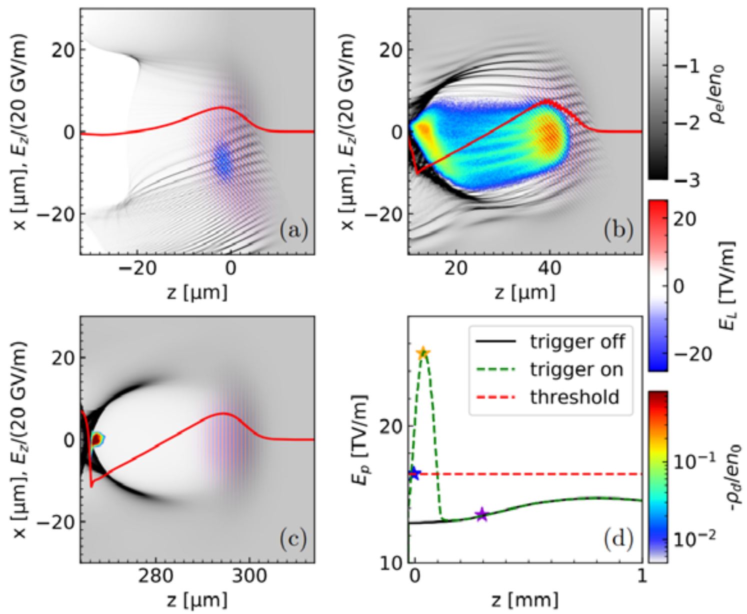
进展4.3 等离子体加速中的可控注入研究-1

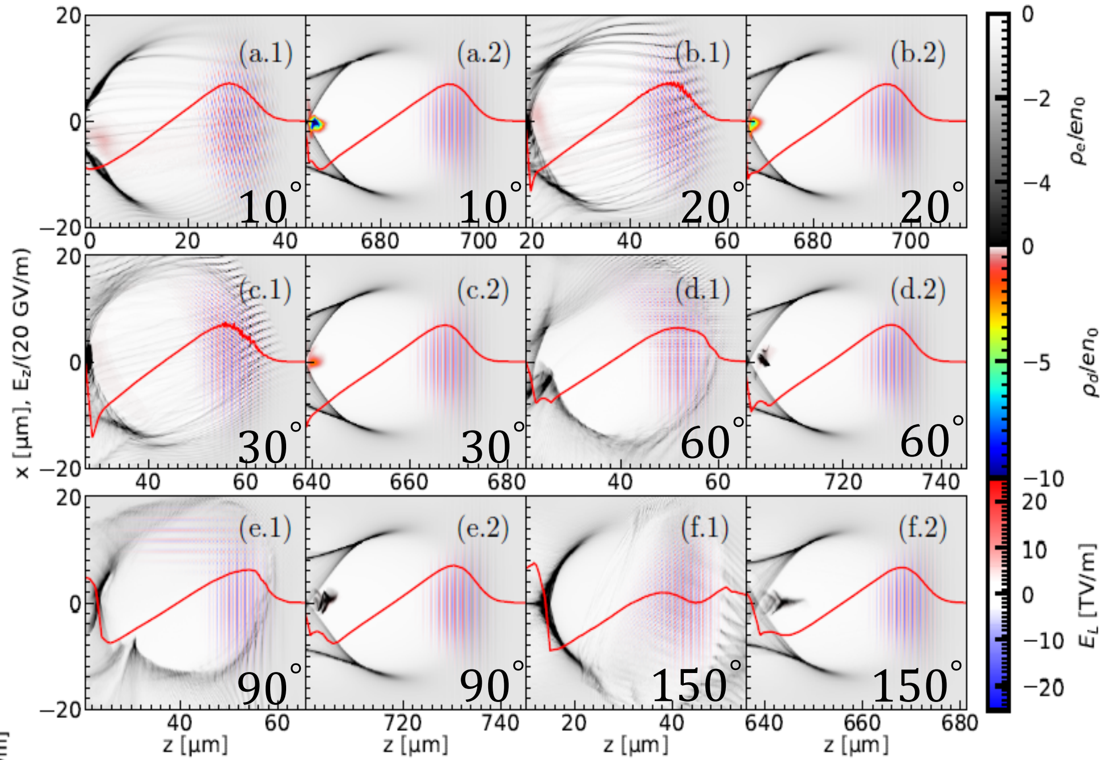




- 在等离子体尾场加速器中提出了新的注入机制
- 产生大电量、低发射度、低片能散电子束
- M. Zeng et al., *New J. Phys.* **22** (2020) 123003 (CAS Q2-top)

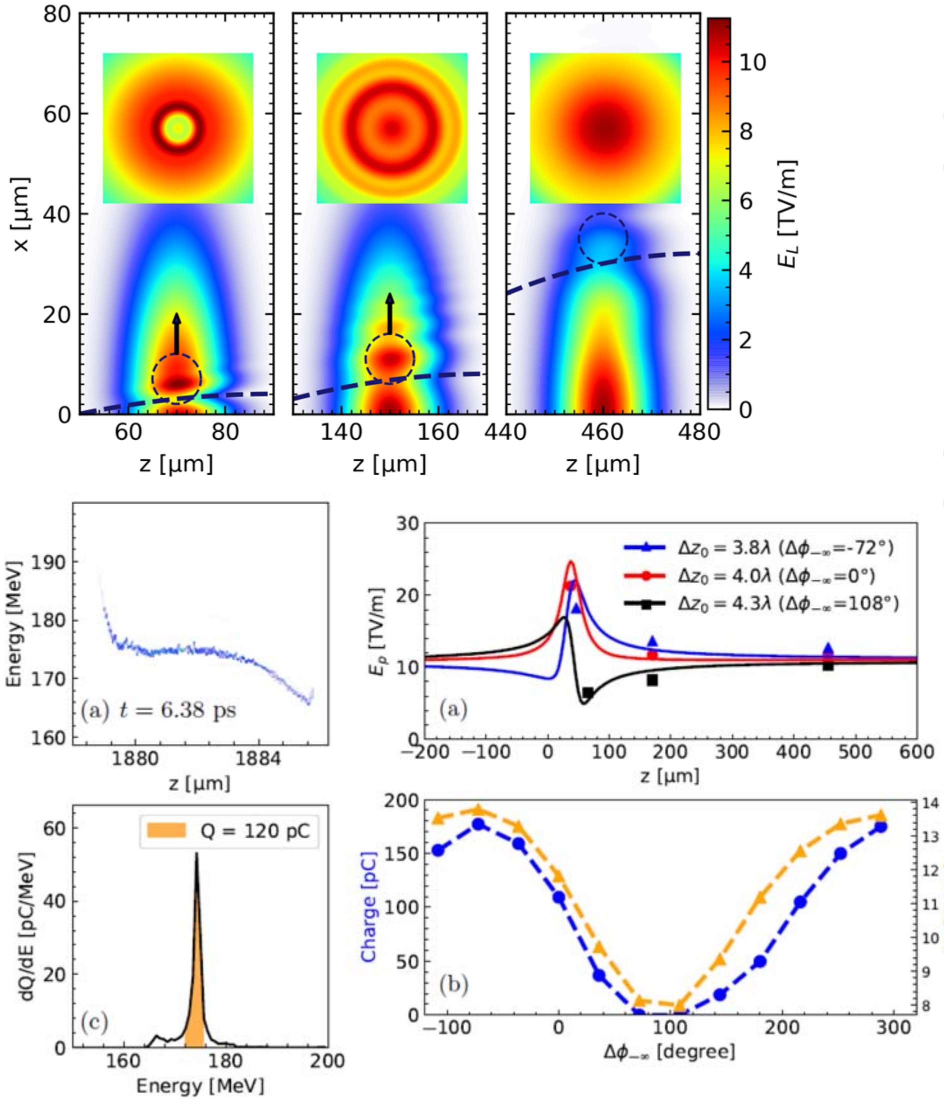


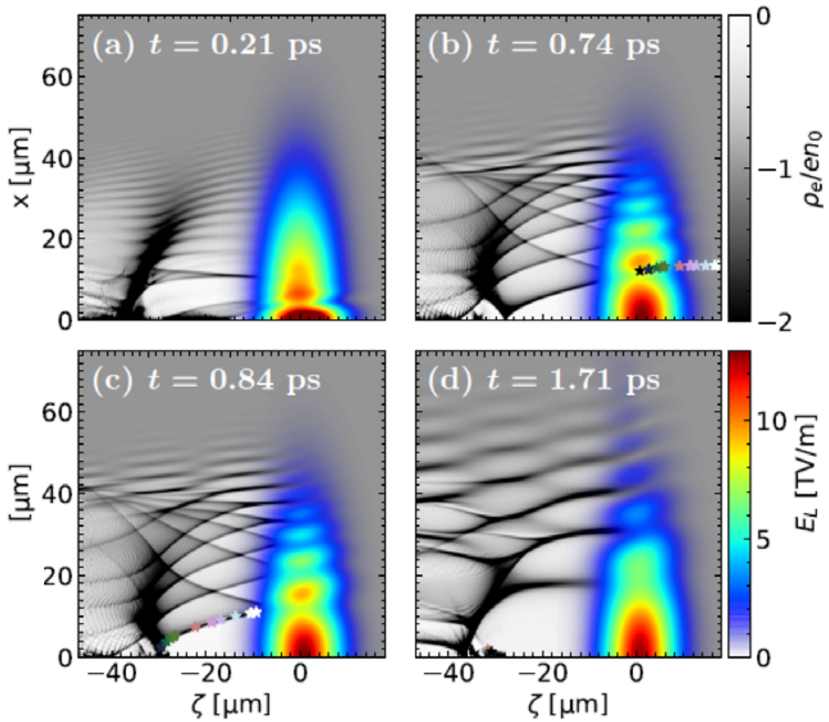




- **In 3D simulation, 100 TW (800nm) + 25 TW (400 nm) @ 8° (should not be the optimized condition), ~ 500 MeV, 40 pC, 1%**
- **In 2D simulation, ΔE/E ~ 0.7% @ ~ 580 MeV**
- **Accepted by PPCF (CAS Q2)**

进展4.3 等离子体加速中的可控注入研究-3

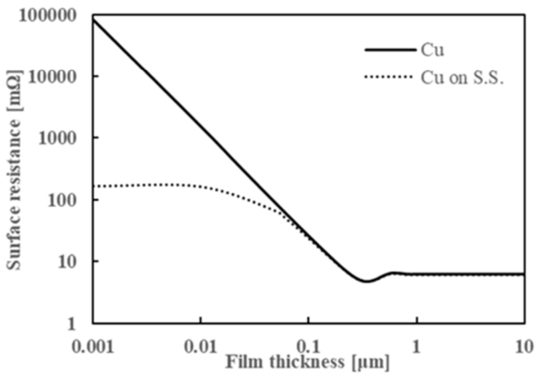


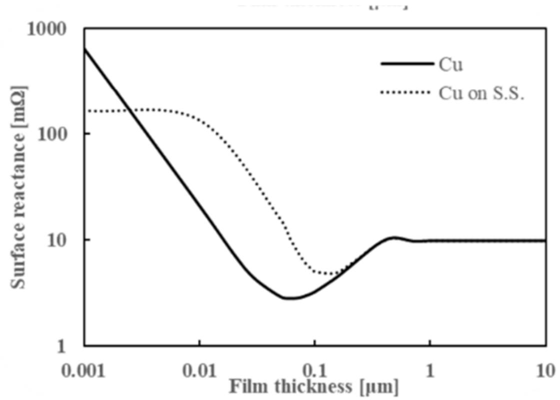


- In simulation, with 230 TW laser, we can get ~ 750 MeV, 130 pC, 0.4% e- beam
- Sensitive to 2-laser time delay (sub fs)
- Propose an realistic experiment @ Huairou
- Manuscript V1.0 is done

进展4.4 计算腔表面效应的软件开发工作

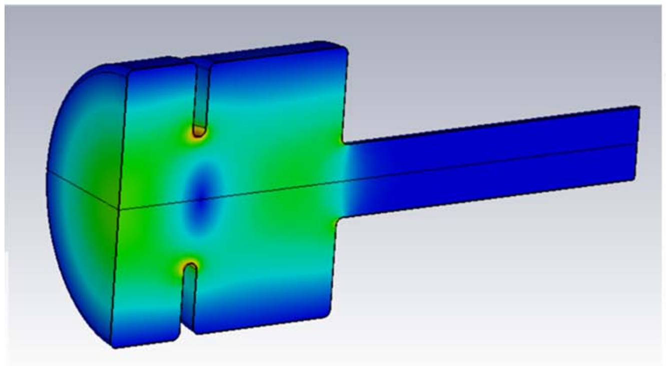
- Anomalous Skin Effect Study:
  - Developed a method to selfconsistently evaluate the anomalous skin effect in normal and superconducting material.
  - The method solves the non-local Maxwell's equations with given boundary conditions.
  - The method predicted a optimoum thickness of the metal film with the purpose of minimizing the RF impedance.



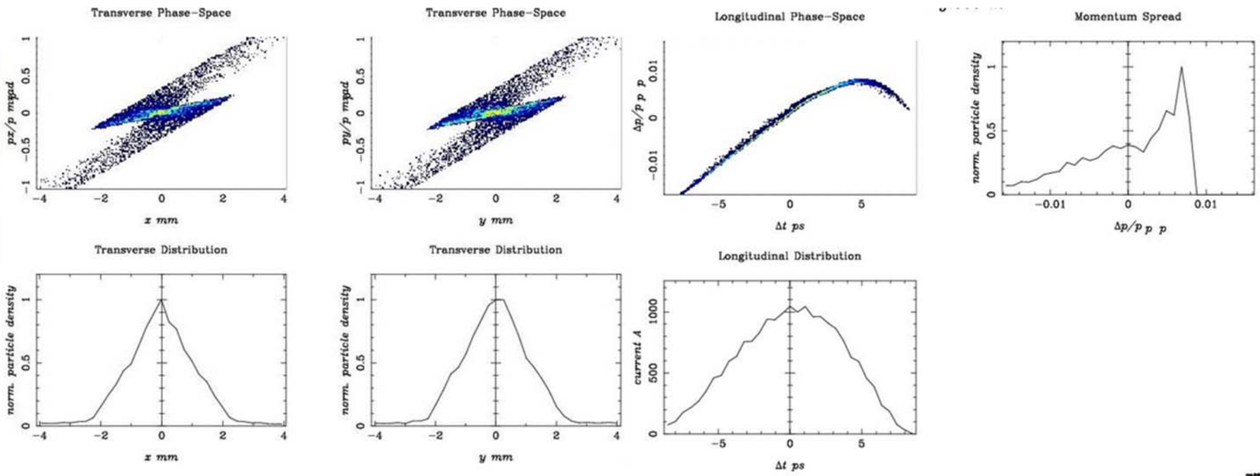


进展4.4 CEPC光阴极电子枪的初步设计

- CEPC related
  - Initiated and proceeding with endeavor of designing the **RF Photo-injector** for CEPC under Prof. Gao Jie's lead.
    - Current progress showed promising results indicating the great potential of the Photo-injector in terms of beam quality and compatibility with future machine upgrade.
    - Both **transverse emittance** (38 um)and **bunch length** (1 mm) meet the LINAC requirement, which is 100 um and 1 mm respectively.
  - Developed the time domain **beam cavity interaction (BCI)** simulation package. The code is ideal for studying the various longitudinal problems including but not limited to coupled bunch mode instability, transient beam loading, HOM power evaluation, etc.



1.5 Cell L-Band Cavity



进展4.4 初步成果汇总

发表文章

- ✓ arXiv 两篇：
  - B Xiao, M Blaskiewicz, **T Xin**, *Anomalous skin effect study of superconducting film*, arXiv preprint arXiv:2101.11678
  - B Xiao, M Blaskiewicz, **T Xin**, *Study of the anomalous skin effect of normal conducting film*, arXiv preprint arXiv:2004.11462
- ✓ 会议报告两篇：
  - **T. Xin**, P. Zhang, H.J. Zheng, et. al. Upgrade of RF system in BEPCII, 第十届全国加速器微波高频技术研讨会（2021），中国甘肃天水。
  - **T. Xin**, A Preliminary Design of RF Photo_Injector for CEPC, IAS Program on High Energy Physics, China, Hongkong, Jan. 13-19, 2022
- ✓ 技术报告一篇：
  - Z. Pei, **T. Xin**, H.J. Zheng, et. al., Design Report of the new RF System in BEPCII, IHEP Internal Note 2021.

专用模拟软件三套：

- ✓ T. Xin, M. Blaskiewicz, BCI, a Beam Cavity Interaction emulator as one of the modules in APES. https://github.com/tianmux/APES
- ✓ T. Xin, Z. K. Chen, RES, a Radio Frequency Structure Eigen Mode Solver, https://github.com/tianmux/FEM
- ✓ T. Xin, pyMOGA for RF Gun design, Internal Archive.

主要内容

- 课题目标及任务
- 课题设立以来的主要进展
- 经费使用情况
- 未来计划及预算

经费使用详情

- 研究经费总和：800w（卓越中心+科学家工作室）+300w（所创新）=1100w
- IHEP自研费用：680w **（340w待付）**
  - ✓ 高能所人员模拟研究所需机时费：30w（已用完）+30w（已支付）=60w
  - ✓ 差旅费+出版发行费：10w
  - ✓ 曾明BR启动经费：100w（还有**100w**待转拨），目前已花费30.2655w（主要为本人绩效）
  - ✓ 辛天牧BR启动经费：160w（还有**240w**待转拨），目前已花费47.2w（主要为本人绩效+服务器及机时购买）
  - ✓ 人员费（已有2名博士+1名博后）：约10w
- 外协研究费用（清华大学）：640.26w **（207w待付）**
  - ✓ 人员及差旅费：100w（还有**200w**待转拨）
  - ✓ 模拟计算机时：30w（已用完）+30w（已支付）=60w
  - ✓ 等离子体气室及相关控制气路：24.243w
    - 42600（脉冲控制器）+62400（gas-cell加工）+64150（真空组件）+73280（气路）
  - ✓ 光学实验常用镜片：73.781743w
    - 284250（反射镜）+217806.9（曲面镜）+185380.53（光栅）+50380（锥透镜）
  - ✓ 电控平移台：79.04w
  - ✓ 激光器研制：76.892w=49.4w（晶体）+20.06w（氙灯电源）+7.432w（水冷机）
  - ✓ 其他实验辅助设备：26.3w=15w（电子能谱仪电源）+4.3w（辐射剂量仪）+7w **（单次自相关仪，待付）**

主要内容

- 课题目标及任务
- 课题设立以来的主要进展
- 经费使用情况
- **未来计划及预算**

未来计划及所需经费

- IHEP自研费用：**340w（待转拨）+160w**
  - ✓ 高能所人员模拟研究所需机时费：**20w/年×3=60w**
  - ✓ 差旅费+出版发行费：**20w**
  - ✓ 曾明BR启动经费：**100w待转拨**
  - ✓ 人员费：计划至少保障3名博士+3名博后，**80w/年**
- 外协研究费用（清华大学）：640.26w **（207w待付）**
  - ✓ 人员及差旅费：100w（还有**200w**待转拨）
  - ✓ 其他实验设备采购计划待定（3月15日之前确定）

Thank you!