粒子物理前沿卓越中心
2020年度考评报告

（CEPC加速器物理设计）

王逗
高能物理研究所

2020年12月5日

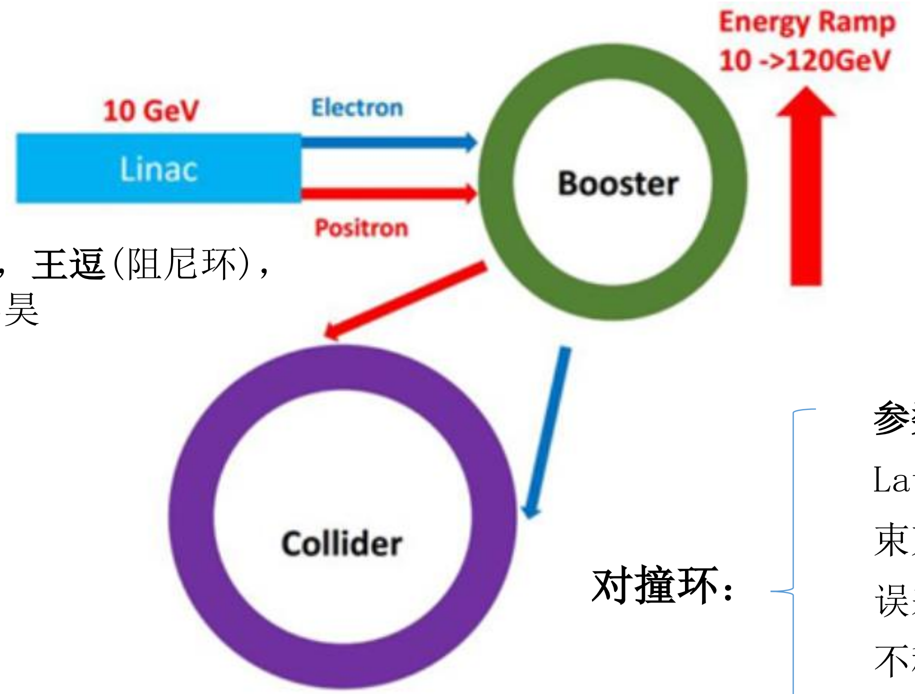
提纲

- CEPC 总体参数设计
- CEPC 增强器物理设计
- CEPC 注入引出方式/时序
- CEPC 阻尼环物理设计
- CEPC 等离子体注入器相关

CEPC加速器物理设计

加速器物理系统负责人：于程辉

亮度目标 → 对撞环（主环) → 增强器 → 直线



增强器：

- **参数设计：王逗** （负责人）
- **Lattice设计：王逗**
- 误差：季大恒
- 不稳定性：刘瑜冬
- 传输线：崔小昊

直线注入器： 孟才，**王逗**(阻尼环)，崔小昊

对撞环：

- **参数设计：王逗**
- Lattice设计：王毅伟
- 束束作用：张源
- 误差：魏源源，王斌
- 不稳定性：王娜，刘瑜冬
- 传输线：崔小昊
- MDI：白莎

注入引出：王逗(总体方案)，崔小昊

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CEPC总体参数新进展

- 新参数表的给出
  - CEPC ttbar参数（180GeV）
  - CEPC高亮度Higgs（120GeV）
    ($2.9\times10^{34}cm^{-2}s^{-1} \rightarrow 5.0\times10^{34}cm^{-2}s^{-1}$)
  - CEPC单cell腔高亮度Z（45.5GeV）
    ($3.2\times10^{35}cm^{-2}s^{-1} \rightarrow 1.0\times10^{36}cm^{-2}s^{-1}$)

- 需要考虑的问题

加速器物理相关

Crab waist 亮度增益
Piwinski angle
大角度等效束长
水平束团尺寸修正
束束作用参数（极限）
beta*选取
动力学孔径(DA)
束长拉伸
发射度选择
束团paton
注入引出方式（时序、时长）
。。。

加速器技术相关

RF腔压选取
流强限
beam loading
对反馈系统的需求
同步辐射功率限制
高次模功率限制

探测器背景相关

束致辐射寿命（能散）
束致辐射光子产额
BB 寿命
touchek寿命
量子寿命

120GeV Higgs能量下高亮度加速器参数

	Higgs (CDR)	*Higgs*
Number of IPs	2	2
Energy (GeV)	120	120
Circumference (km)	100	100
SR loss/turn (GeV)	1.73	1.8
Half crossing angle (mrad)	16.5	
Piwinski angle	3.48	4.87
N_e/bunch (10^{10})	15.0	16.3
Bunch number	242	214
Beam current (mA)	17.4	16.8
SR power /beam (MW)	30	30
Bending radius (km)	10.7	10.2
Momentum compaction (10^{-6})	11.1	7.34
β_{IP} x/y (m)	0.36/0.0015	0.33/0.001
Emittance x/y (nm)	1.21/0.0024	0.64/0.0013
Transverse σ_{IP} (um)	20.9/0.06	15.0/0.037
ξ_x/ξ_y/IP	0.018/0.109	0.018/0.115
V_{RF} (GV)	2.17	2.27
f_{RF} (MHz) (harmonic)	650 (217500)	
Nature bunch length σ_z (mm)	2.72	2.25
Bunch length σ_z (mm)	4.4	4.42
Energy spread (%) (SR/BS)	0.1/0.134	0.1/0.19
Energy acceptance requirement (%)	1.35	1.7
Energy acceptance by RF (%)	2.06	2.5
Lifetime due to beamstrahlung (min)	80	41
Lifetime (min)	25	21
F (hour glass)	0.89	0.88
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	**2.93**	**5.0**

D. Wang, C. H. Yu, Y. Zhang, Y. W. Wang,...

Improvement of key parameters

- Higher bunch charge & larger Piwinski angle
- Smaller emittance & βy*
- Smaller βx* to control ξx
- Requirement for DA energy spread: 1.35%→1.7%

CEPC high luminosity Higgs:

$L = \mathbf{2.9\times10^{34}cm^{-2}s^{-1} \rightarrow 5.0\times10^{34}cm^{-2}s^{-1}}$

45GeV Z能量下参数优化

- **Difficulty in CDR parameter**
  - 自洽的考虑束束作用和阻抗影响，发现工作点稳定区极小，设计亮度难实现*
- **Parameter update for Z**: L = **3.2×10^35^cm^-2^s^-1^ → 1.0 ×10^36^cm^-2^s^-1^**
  - 弧区磁聚焦结构相依优化: 90° FODO → 60° FODO
  - 增大发射度 & αp
  - 减小βx*， 控制ξx → 扩大工作点稳定区
  - 同步地减弱束束不稳定性和阻抗不稳定性 → 提高单束流强限
  - 在Z能量下采用单cell超导腔 → 降低HOM功率**
  - 提升束流SR功率：16.5MW→30MW

* Yuan Zhang, CEPC day, July 24th, 2020.

**Jiyuan Zhai, CEPC day, Sep. 23th, 2020.

CEPC 高亮度Z参数

D. Wang, Y. Zhang, N. Wang, C. H. Yu, J. Zhai…

	Z-CDR	*Z*
Number of IPs	2	2
Energy (GeV)	45.5	45.5
Circumference (km)	100	100
SR loss/turn (GeV)	0.036	0.036
Half crossing angle (mrad)	16.5	16.5
Piwinski angle	23.8	18.0
N_e/bunch (10^{10})	8.0	16.1
Bunch number	**12000**	**10870 (27ns)**
Beam current (mA)	**461**	**841.0**
SR power /beam (MW)	**16.5**	**30**
Bending radius (km)	10.7	10.7
Phase advance of arc cell	90°/90°	60°/60°
Momentum compaction (10^{-5})	1.11	2.23
β_{IP} x/y (m)	0.2/0.001	0.15/0.001
Emittance x/y (nm)	0.18/0.0016	0.52/0.0016
Transverse σ_{IP} (um)	6.0/0.04	8.8/0.04
ξ_x/ξ_y/IP	0.004/0.079	0.0048/0.129
V_{RF} (GV)	0.1	0.13
f_{RF} (MHz) (harmonic)	650	650
Nature bunch length σ_z (mm)	2.42	2.93
Bunch length σ_z (mm)	8.5	9.6
Energy spread (%)	0.08	0.12
Energy acceptance (DA) (%)	1.5	1.4
Energy acceptance by RF (%)	1.7	1.5
Lifetime (hour)	2.5	1.8
L_{max}/IP (10^{34}cm^{-2}s^{-1})	**32.1**	**101.1**

➢ Improvement of key parameters

- 90°/90 ° → 60°/60 °
  - εx: 0.18nm → 0.52nm
  - α_p: 1.11 × 10^{-5} → 2.23 × 10^{-5}
  - εy: 1.6pm → 1.6pm (0.88% →0.3%)
- Increase bunch length: 11.9mm→ 13.2mm
  - ξx: 0.0029 →0.00256
  - ξy: 0.097 →0.094
  - Ne: 8 × 10^{10} →16.1 × 10^{10}
  - ξx/νs: 0.214 →0.112
- Microwave instability threshold $N_{th} \propto \frac{\alpha_p \sigma_p^2 \sigma_z}{\mathrm{Re}[Z/n]}$
  - Threshold ×~2

CEPC ttbar 参数@180GeV

D. Wang, C. H. Yu, Y. Zhang, Y. W. Wang,...

	tt	*Higgs*	*W*	*Z*
Number of IPs	2	2	2	2
Energy (GeV)	180	120	80	45.5
Circumference (km)	100	100	100	100
SR loss/turn (GeV)	8.53	1.73	0.34	0.036
Half crossing angle (mrad)	16.5	16.5	16.5	16.5
Piwinski angle	0.9	3.48	7.0	18.0
N_e/bunch (10^{10})	26.1	15.0	12.0	16.1
Bunch number	28 (10.7μs)	242 (0.68μs)	1524 (0.21μs)	10870 (27ns)
Beam current (mA)	3.52	17.4	87.9	841.0
SR power /beam (MW)	**30**	**30**	**30**	**30**
Bending radius (km)	10.7	10.7	10.7	10.7
Phase advance of arc cell	90°/90°	90°/90°	90°/90°	60°/60°
Momentum compaction (10^{-5})	1.11	1.11	1.11	2.23
β_{IP} x/y (m)	1.2/0.0037	0.36/0.0015	0.36/0.0015	0.15/0.001
Emittance x/y (nm)	2.4/0.0072	1.21/0.0024	0.54/0.0016	0.52/0.0016
Transverse σ_{IP} (um)	53.7/0.17	20.9/0.06	13.9/0.049	8.8/0.04
ξ_x/ξ_y/IP	0.077/0.105	0.018/0.109	0.013/0.123	0.0048/0.129
V_{RF} (GV)	9.9	2.17	0.47	0.13
f_{RF} (MHz) (harmonic)	650 (216816)	650 (216816)	650 (216816)	650 (216816)
Nature bunch length σ_z (mm)	2.59	2.72	2.98	2.93
Bunch length σ_z (mm)	2.91	4.4	5.9	9.6
Energy spread (%)	0.16	0.134	0.098	0.12
Energy acceptance (DA) (%)	1.7	1.35	0.90	1.4
Energy acceptance by RF (%)	2.6	2.06	1.47	1.5
Lifetime (hour)	0.67	0.43	1.4	1.8
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	**0.34**	**2.93**	**10.1**	**101.1**

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增强器兼容性设计

- 新参数表的给出
  - booster ttbar参数（180GeV）

    能量跨度扩大：10GeV/120GeV→10GeV/180GeV
  - booster 参数@高亮度Z

    提升流强承载能力：7mA→14mA

- 需要考虑的问题

低能（高能）流强限
束团分布pation，反馈系统需求
注入引出方式（时序、时长）
纵向接收度范围
纵向工作点
主环空环注入时长。。。

RF功率决定的流强限
kicker重频的选择
注入引出系统的兼容性
最大高频腔压
二极铁低场重复性/均匀性
电源动态跟踪精度/同步性

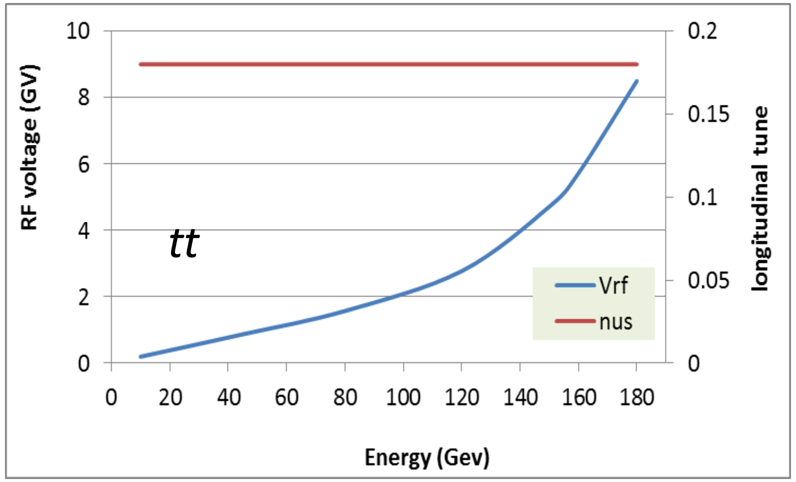
		tt	***H***	***W***	***Z***	***Z* (high lum.)**
Beam energy	GeV	10				
Bunch number		28	242	1524	6000	5435
Threshold of single bunch current	µA	25.7				
Threshold of beam current (limited by coupled bunch instability)	mA	100				
Bunch charge	nC	1.39	0.78	0.63	0.45	0.9
Single bunch current	µA	4.2	2.3	1.8	1.3	2.6
Beam current	mA	0.12	0.57	2.86	7.51	13.9
Energy spread	%	0.0078				
Synchrotron radiation loss/turn	keV	73.5				
Momentum compaction factor	10^{-5}	2.44				
Emittance	nm	0.025				
Natural chromaticity	H/V	-336/-333				
RF voltage	MV	193	101	62.7		
Betatron tune $\nu_x/\nu_y/\nu_s$		263.18/261.28/0.18	263.18/261.28/0.13	263.18/261.28/0.		
RF energy acceptance	%	3.4	2.5	1.9		
Damping time	s	90.7				
Bunch length of linac beam	mm	1.0				
Energy spread of linac beam	%	0.16				
Emittance of linac beam	nm	40				

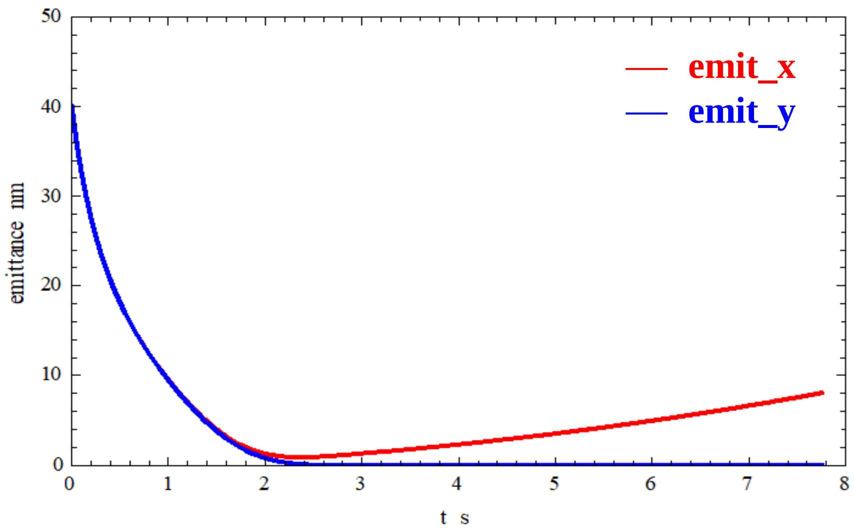
		tt		***H***		***W***	***Z***	***Z* (high lum.)**
		Off axis injection	On axis injection	Off axis injection	On axis injection	Off axis injection	Off axis injection	
Beam energy	GeV	180		120		80	45.5	
Bunch number		28	27+1	242	235+7	1524	6000	5435
Maximum bunch charge	nC	1.25	43	0.72	24.0	0.58	0.41	0.81
Maximum single bunch current	µA	3.8	131	2.1	70	1.7	1.2	2.34
Threshold of single bunch current	µA	730		300				
Threshold of beam current (limited by RF power)	mA	0.5		1.0		4.0	10.0	14
Beam current	mA	0.11	0.23	0.52	1.0	2.63	6.91	12.5
Injection duration for top-up (Both beams)	s	31.5	35	25.8	35.4	45.8	275.2	144*
Injection interval for top-up	s	73		47.0		153.0	504.0 / 274.1	197
Current decay during injection interval		3%						
Energy spread	%	0.14		0.094		0.062	0.036	
Synchrotron radiation loss/turn	GeV	7.7		1.52		0.3	0.032	
Momentum compaction factor	10^{-5}	2.44						
Emittance	nm	8.0		3.57		1.59	0.51	
Natural chromaticity	H/V	-336/-333						
Betatron tune ν_x/ν_y		263.18/261.28						
RF voltage	GV	**8.5**		1.97		0.585	0.287	
Longitudinal tune		0.18		0.13		0.10	0.10	
RF energy acceptance	%	0.85		1.0		1.2	1.8	
Damping time	ms	15.5		52		177	963	
Natural bunch length	mm	3.0		2.8		2.4	1.[illegible]	
Injection duration from empty ring	h	0.15		0.17		0.25	2.2	2.5*

增强器ttbar模式升能分析

- **确认180GeV 运行可以实现**
  - 动态束流参数解析计算
  - 升能时序设计
  - 高频升能曲线

- **Different RF ramping curve for each energy mode**
  - vs for *tt*: 0.18
  - vs for Higgs: 0.13
  - vs for W & Z: 0.1
- **Max RF voltage @*tt* determined by longitudinal quantum lifetime.**
  - η_{RF}: ~ 6 ×δ
  - VRF (180GeV)=8.5GV





增强器带误差动态升能模拟

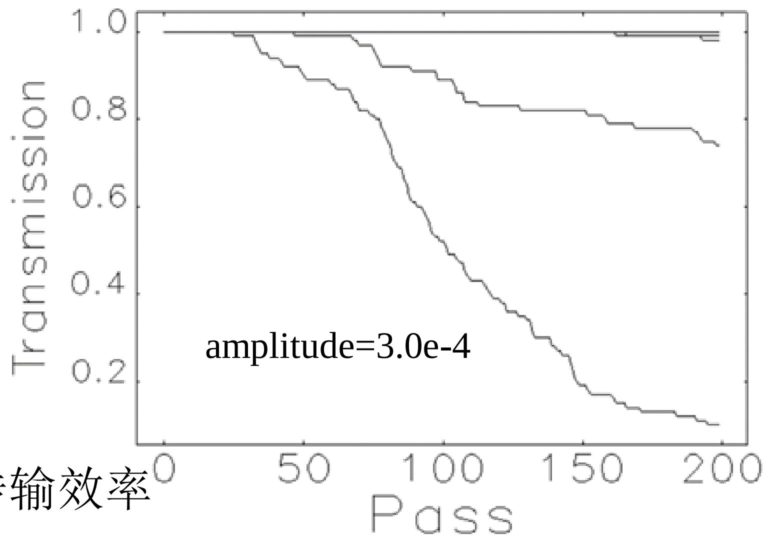
D. Wang, X. N. Wang, C. Meng,
D. H. Ji, C. H. Yu…

- 动态升能模拟→ 定量化的传输效率
- 研究提升传输效率的手段
  - 引入尽可能全面、实际的误差种类
  - 找不到闭合轨道，传输效率为 0
  - 两步法轨道校正
    - Sex off → sex open
  - 轨道校正后传输效率：100%

parameters	Dipole	Quadrupole	Sextupole
Transverse shift x/y (um)	100	100	100
Longitudinal shift z (um)	100	100	100
Tilt about z (urad)	100	100	100
Nominal field	2×10^{-3}	2×10^{-4}	3×10^{-4}

	dipole	quadrupole	sextupole
n=1, N/S	$3\times10^{-4}/3\times10^{-4}$		
n=2, N/S	$1\times10^{-5}/1\times10^{-5}$	$4.5\times10^{-4}/4.5\times10^{-4}$	
n=3, N/S	$1\times10^{-6}/1\times10^{-6}$	$2.5\times10^{-5}/2.5\times10^{-5}$	$2\times10^{-3}/2\times10^{-3}$
n=4, N/S	$5\times10^{-7}/5\times10^{-7}$	$2.5\times10^{-5}/2.5\times10^{-5}$	$1\times10^{-4}/1\times10^{-4}$
n=5, N/S	$5\times10^{-7}/5\times10^{-7}$		$1\times10^{-4}/1\times10^{-4}$
n=6, N/S	$2\times10^{-7}/2\times10^{-7}$		$1\times10^{-4}/1\times10^{-4}$

- 磁铁电源跟踪精度及同步性的容忍度
  - 动态过程中磁铁电源与理想值存在偏差—跟踪精度
  - 大量电源很难保证完全步调一致的升能—同步性
  - 动态误差无法校正
  - 优化目标：传输效率>95%
  - 磁铁电源跟踪精度/同步性容忍度：~ 3×10^{-4} (RMS)



- 列表升能方案 — 所有电源精确的步调一致的升能 — 确保传输效率

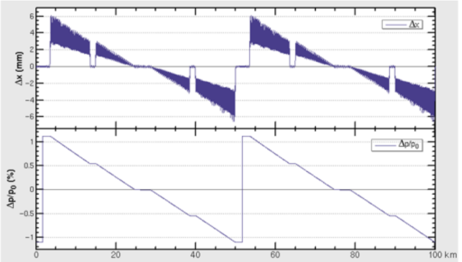
ttbar 模式强同步辐射问题

D. Wang, D. H. Ji

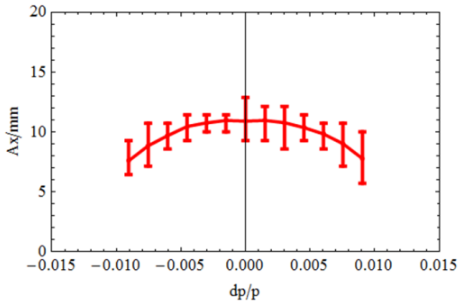
- **Problems:**
  - 仅有2个高频站，束流能量沿环差异大：1.1%
  - 最大轨道误差: 6 mm
  - 发射度增长: ~3.6%
  - 于其他误差并存.

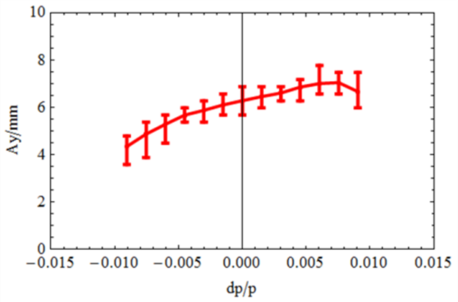
- **Possible solutions:**
  - 所有四、六极铁按能量做强度调节
  - 二极铁分区调节（8区，串联供电）
  - 轨道校正（optics 校正）
- **减低粒子丢失率→ 高传输效率**

W/O taper



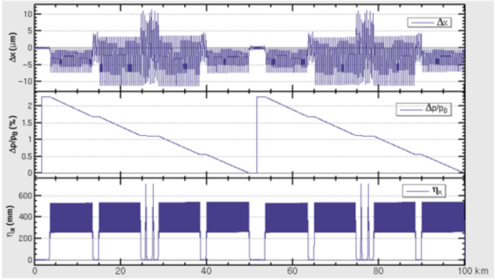
- DA > requirement (BSC)
  - BSCX=4σx+3mm=7.7mm
  - BSCY=4σx+3mm=3.3mm
- Need careful error study

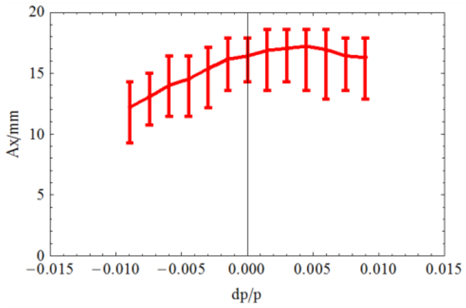


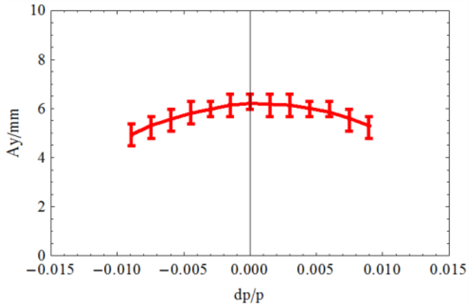


W taper

- sawtooth orbit was corrected by tapering
- DA tracking w/o errors (50 seeds, 100 turns)
- DA is good enough



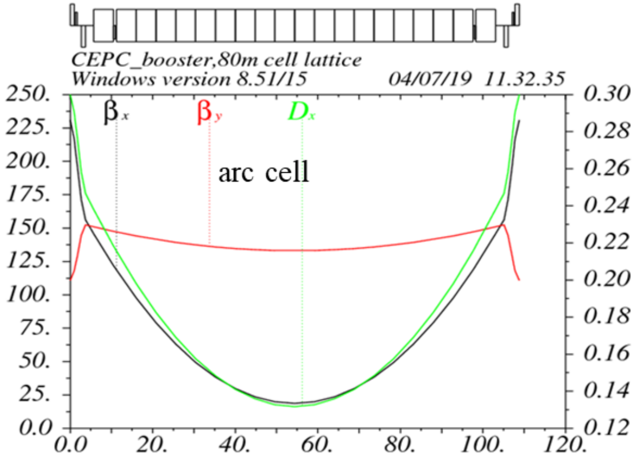


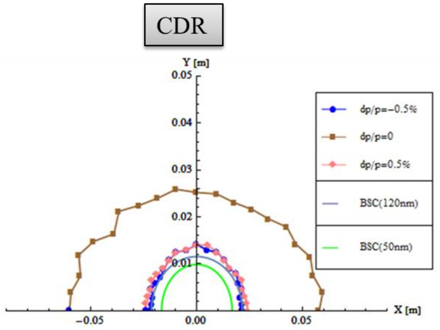


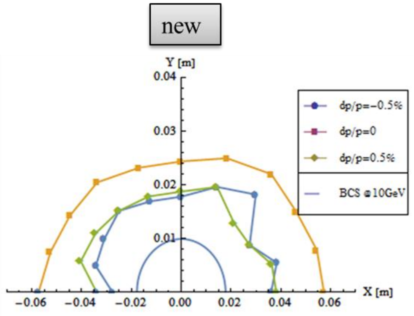
小发射度增强器设计-TME

D. Wang, Y. M. Peng, C. H. Yu, D. H. Ji

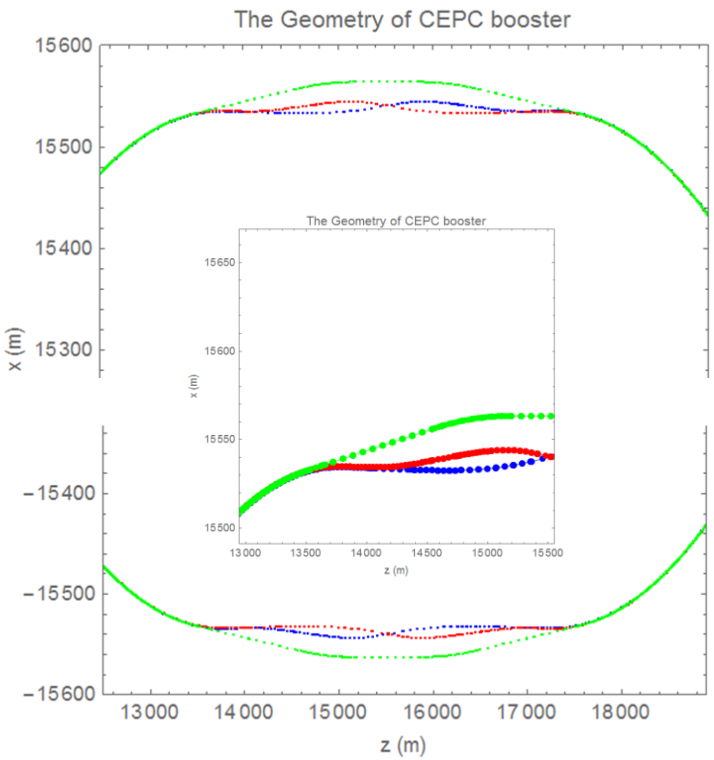
- 对撞机更高亮度→ 对撞环更小发射度→ 增强器更小发射度
- 满足主环高亮度higgs的注入需求
- 难度向前级传导/转移
- 对DA需求增大
- 几何设计— 保证与主环共享隧道
- 完成参数表更新
- 耦合度需求：0.5% → 1.4%







- Emittance: 3.57nm → 1.29nm



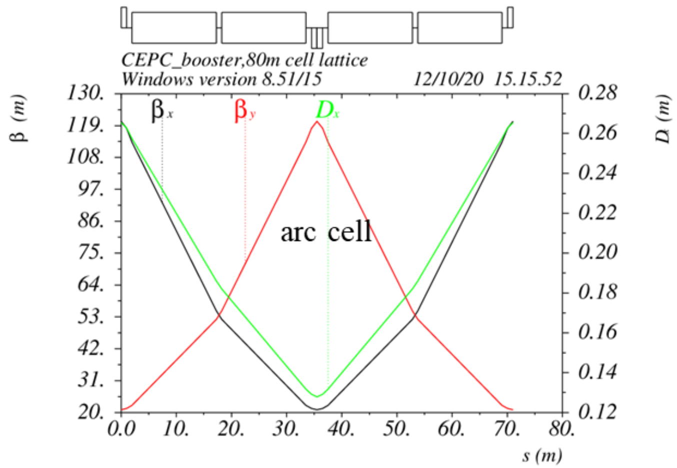
- Exact geometry match for three rings
  -- error=±0.17m

小发射度增强器备选方案-FODO

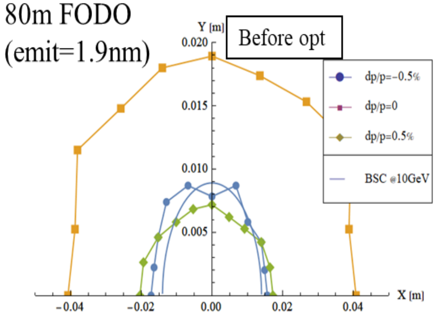
- FODO结构的优点：对误差敏感度低， 缺点：相同发射度时DA比TME小
- 最终方案选定需要综合评估多方因素

误差敏感度，误差校正难度，主环DA（含误差），damping ring能力，造价

- 90°/ 90° FODO cell
- FODO length: 70m~80m
- Noninterleave sextupole scheme

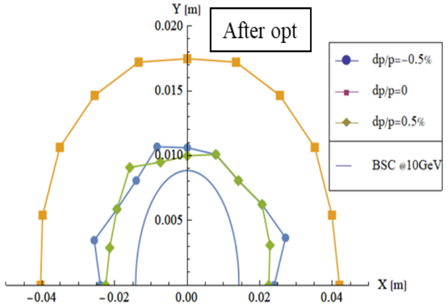


- 80m FODO (emit=1.9nm)

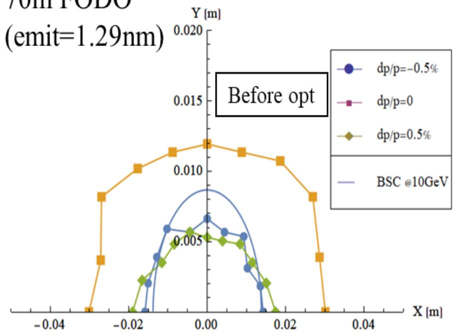


6*FODO5,
FODO,
6*FODO5,
FODO,
6*FODO5,
FODO,
6*FODO5

45° phase in short straight section

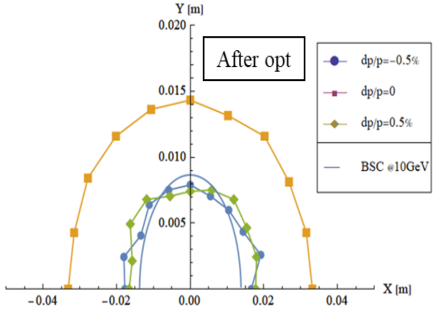


- 70m FODO (emit=1.29nm)



7*FODO5,
7*FODO5,
7*FODO5,
7*FODO5

45° phase in short straight section



提纲

- CEPC 总体参数设计
- CEPC 增强器物理设计
- CEPC 注入引出方式/时序
- CEPC 阻尼环物理设计
- CEPC 等离子体注入器相关

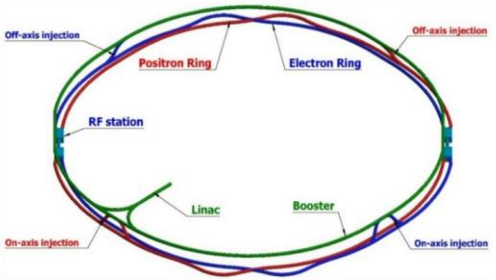
ttbar及高亮度Z注入引出方式/时序

D. Wang, X. H. Cui, C. H. Yu

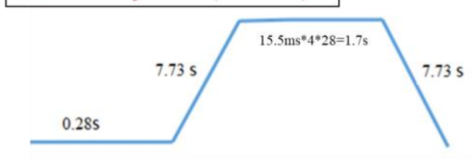
ttbar

- Higher energy (180GeV) can be realized by stronger kickers/septa or longer kickers/septa (enough space)
- Inj./ext. hardware is not a issue for ttbar.

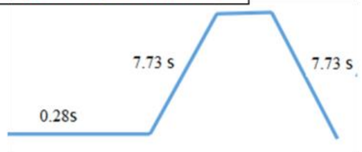
- On-axis injection in vertical plane with vertical local bump for booster
  - top up injection: 35s
- Off-axis injection with horizontal bump for collider
  - top up injection: 31.5s

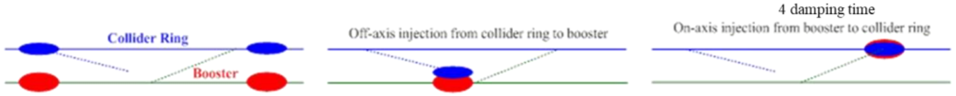


tt on-axis injection (baseline)



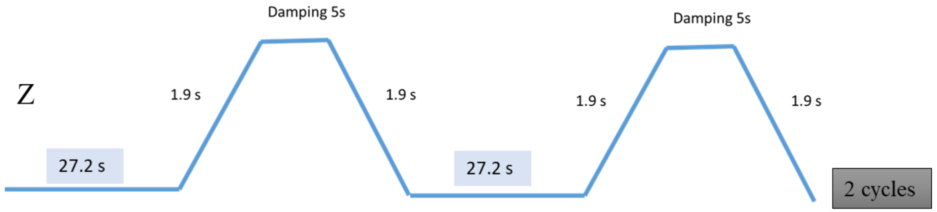
tt off-axis injection (alternative)



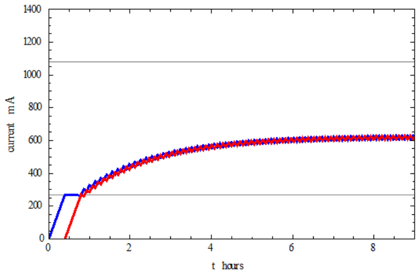


High lum. Z

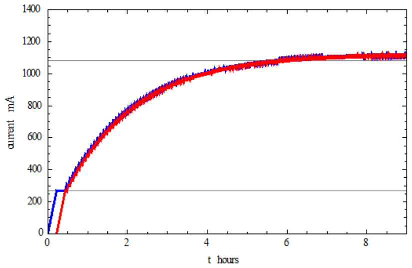
- Injection speed of Linac needs to be improved.
  - Two bunches/pulse
  - Repetition: 200Hz



CDR Linac



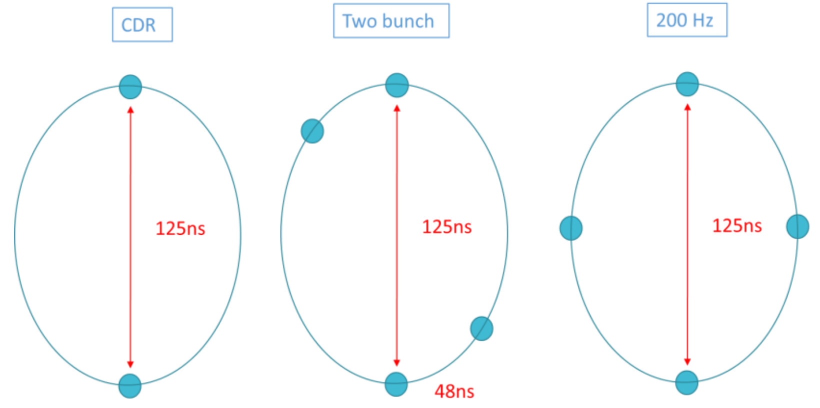
faster Linac (×2)



高亮度Z直线升级方案注入引出方式/时序

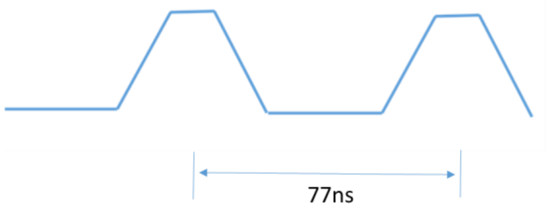
D. Wang, C. Meng, J. H. Chen, C. H. Yu…

Damping ring注入



Booster注入

- 错相触发
- 束团间距：77/4=19.25ns
- Bunch by bunch
- Kicker 起降时间：<19.25ns



- 一台kicker+两台脉冲源
- 两台kicker+两台脉冲源

	inj(Z_CDR)	inj(Z_new) 直线200Hz重复频率	inj(Z_new) 直线双束加速
Energy (GeV)	1.1	1.1	1.1
Bunch number	2	4	4
Bunch separation (ns)	125	62.5	20
Inj/ext scheme	Bunch by bunch	Bunch by bunch	Two by two
Bunch number/train			2
Train number			2
Train separation (ns)			105
Kicker repetition (Hz)	100	200	100
Kicker pulse duration (ns)	250	125	230
Kicker flat top (ns)			20
Kicker speed for rise up/down (ns)	<125	<62.5	<105
Timing delay (ns)	<125	<62.5	<125
Kicker angle (mrad)	1.5	1.5	1.5
Kicker integrated strength (T.m)	0.006	0.006	0.006

	inj(Z_CDR)	inj(Z_new) 直线200Hz重复频率	inj(Z_new) 直线双束加速
Energy (GeV)	10	10	10
Bunch number	6000	7500	7500
Bunch separation (ns)	25	20	20
Inj/ext scheme	Bunch by bunch	Bunch by bunch	Two by two
Bunch number/train	80	100	100
Train number	75	75	75
Train separation (us)	2.46	2.46	2.46
Kicker repetition (Hz)	100	200	100
Kicker pulse duration (ns)	50	40	60
Kicker flat top (ns)			20
Kicker speed for rise up/down (ns)	25	20	20
Timing delay (us)	<2.46	<2.46	<2.46
Injection time (s)	60	37.5	37.5
Kicker angle (mrad)	0.11	0.11	0.11
Kicker integrated strength (T.m)	0.004	0.004	0.004

提纲

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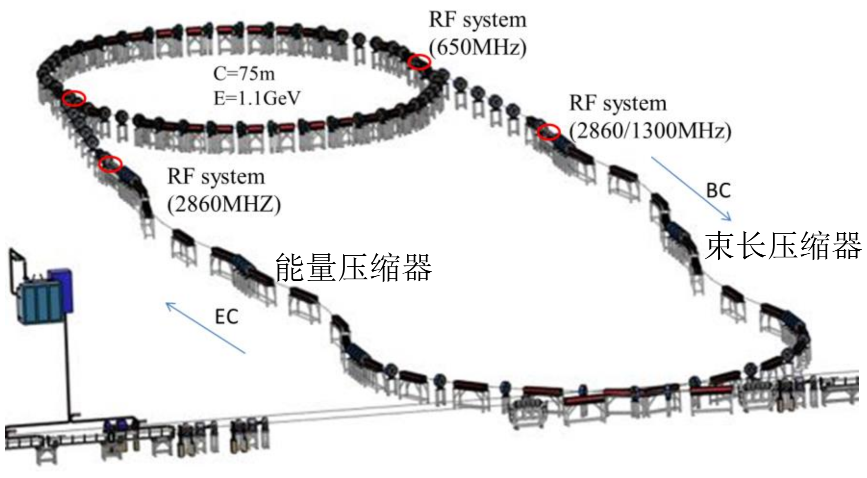
CEPC正电子阻尼环设计

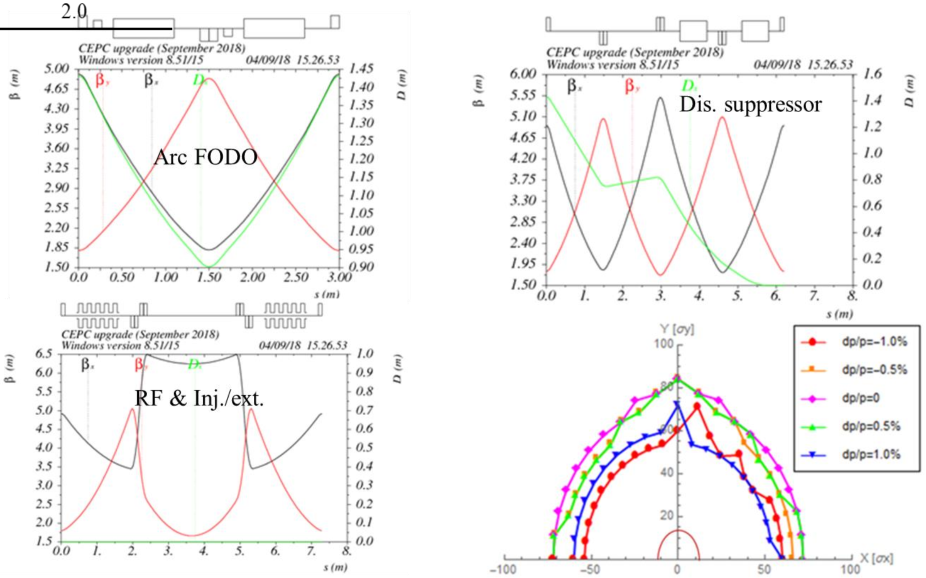
D. Wang, C. Meng, Y. D. Liu…

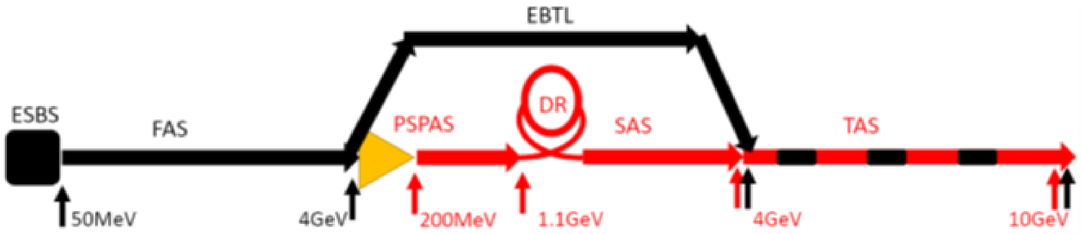
- 减小正电子发射度以满足增强器注入需求
- 阻尼时间足够快
- 高亮度Z模式兼容性

  阻抗不稳定性、电子云、CSR、IBS
- 下一步：进一步减小发射度
  - Linac repetition: 100Hz
  - two-bunch storage scheme
  - Storage time: 20 ms
  - Emittance (norm.): 2500→ 530 mm.mrad
  - Large trans. acceptance→ inj. efficiency

	DR V2.0
Energy (Gev)	1.1
Circumference (m)	75.4
Bending radius (m)	3.6
Dipole strength B_0 (T)	1.03
U_0 (kev/turn)	36.3
Damping time x/y/z (ms)	15.2/15.2/7.6
δ_0 (%)	0.05
ε_0 (mm.mrad)	376.7
injection σ_z (mm)	5
Extract σ_z (mm)	7.5
ε_{inj} (mm.mrad)	2500
$\varepsilon_{ext\ x/y}$ (mm.mrad)	530/180
$\delta_{inj}/\delta_{ext}$ (%)	0.18 /0.05
Energy acceptance by RF(%)	1.0
f_{RF} (MHz)	650
V_{RF} (MV)	2.0







能量压缩器/束长压缩器设计

D. Wang, X. H. Cui

阻尼环与直线加速器之间的桥梁

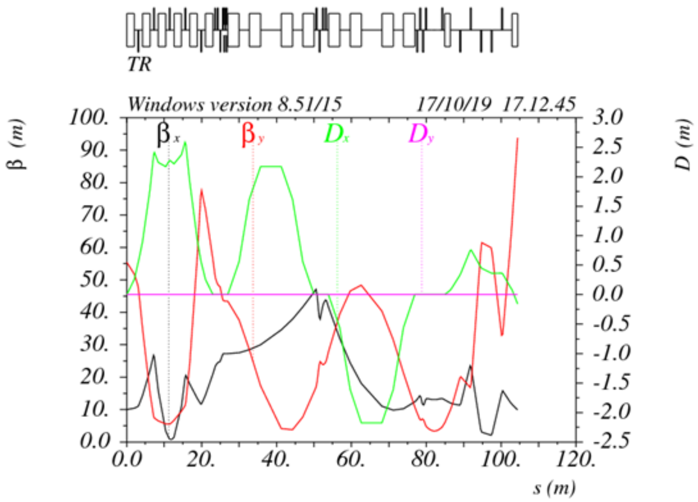
- **Energy compressor**: match the RF acceptance of damping ring
- **Damping ring**: reduce emittance of positron beam
- **Bunch compressor**: reduce bunch length to control energy spread in Linac

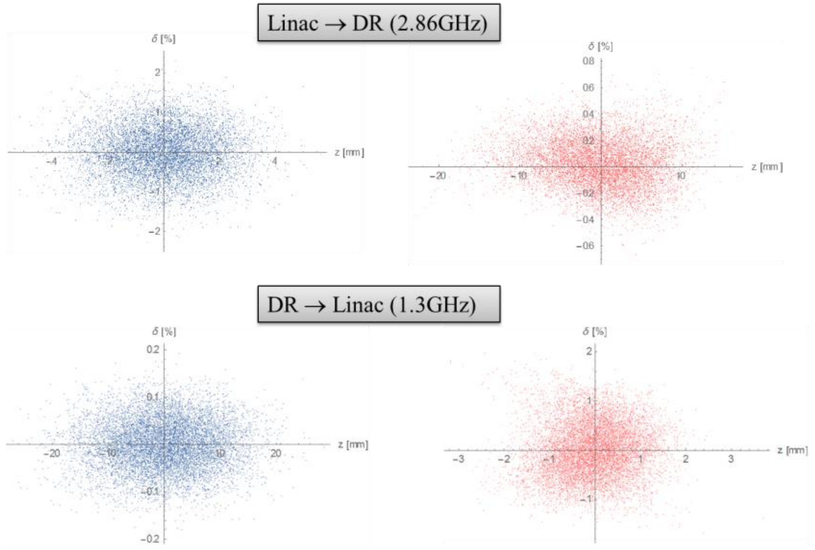
Linac — Parameter exchange

Parameter exchange — Linac

	EC
E_0 (Gev)	1.1
δ_0 (%)	0.6
σ_{z0} (mm)	1.5
f_{RF} (MHz)	2860
V_{RF} (MV)	22.0
Length of acc. Structure (m)	0.82
ϕ_{RF} (degree)	89.7
R_{56} (m)	-0.833
E_f (Gev)	1.1
δ_f (%)	0.18
σ_{zf} (mm)	5

	BC
E_0 (Gev)	1.1
δ_0 (%)	0.05
σ_{z0} (mm)	7.5
f_{RF} (MHz)	2860/1300
V_{RF} (MV)	13.1/29
Length of acc. Structure (m)	0.48/2.5
ϕ_{RF} (degree)	89.6
R_{56} (m)	-1.4
E_f (Gev)	1.1
δ_f (%)	0.54
σ_{zf} (mm)	0.7





提纲

- CEPC 总体参数设计
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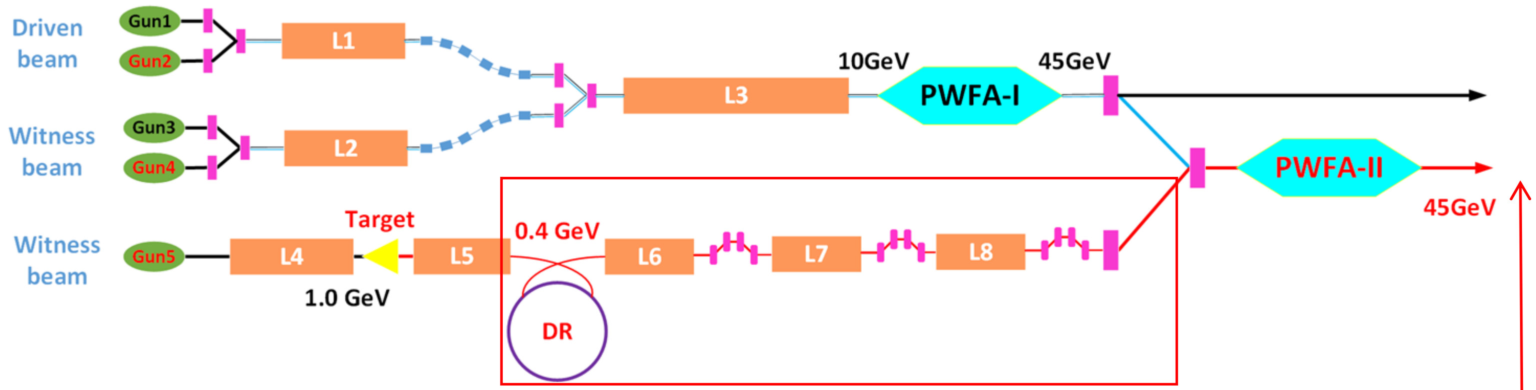
- CEPC 等离子体注入器相关

CEPC 等离子体注入器相关

D. Wang, X. H. Cui, C. Meng,
W. Lu, D. Z. Li, X. N. Wang…



Parameter	Symbol	Unit	Requirement	Realized
e^-/e^+ beam energy	E_e/E_{e+}	GeV	45.5	45.3(-)/45.2(+)
frequency	f_{rep}	Hz	100	100
e^-/e^+ bunch population	N_e/N_{e+}	nC	> 1.0	1.0(-)/1.0(+)
Energy spread (e^-/e^+)	σ_e		$< 2\times10^{-3}$	0.002(-)/0.0014(+)
Emittance (e^-/e^+)	ε_r	nm· rad	< 30	1.89(-)/1.0(+)
Bunch length (e^-/e^+)	σ_l	mm	< 3	0.3(-)/0.3(+)
Switch time e^-/e^+		s	< 20	
Energy stability			$< 2\times10^{-3}$	
Longitudinal stability		mm	< 2	
Orbit stability		mm	<5 (H) / 3 (V)	
Failure rate		%	< 1	

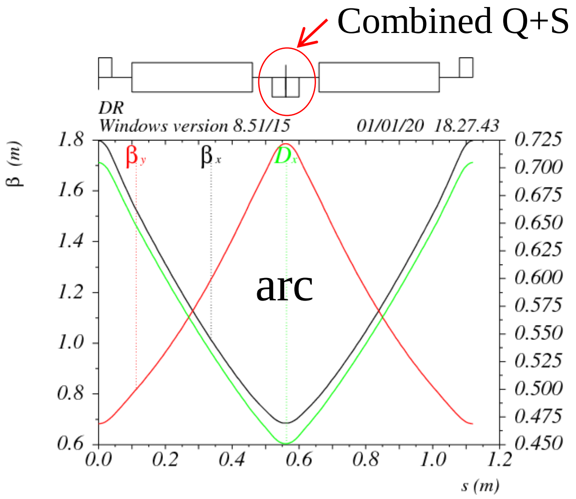
Parameter	Symbol	Unit	Requirement	Realized
e^-/e^+ beam energy	E_e/E_{e+}	GeV	120 (180)	?
frequency	f_{rep}	Hz	100	100
e^-/e^+ bunch population	N_e/N_{e+}	nC	> 1.0	?
Energy spread (e^-/e^+)	σ_e		$< 1.3\times10^{-3}$	?
Emittance (e^-/e^+)	ε_r	nm· rad	<3.6(H)/0.06(V)	?
Bunch length (e^-/e^+)	σ_l	mm	< 2.8	?
Switch time e^-/e^+		s	< 3	?
Energy stability			$< 1.3\times10^{-3}$	
Longitudinal stability		mm	< 4	
Orbit stability		mm	<4 (H) / 0.2 (V)	
Failure rate		%	< 1	

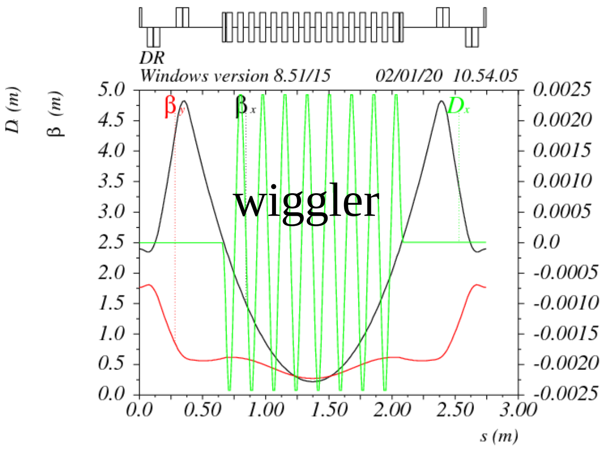
- CEPC与等离子体加速器的接口 （45GeV & 120 GeV）
- 正电子cooling

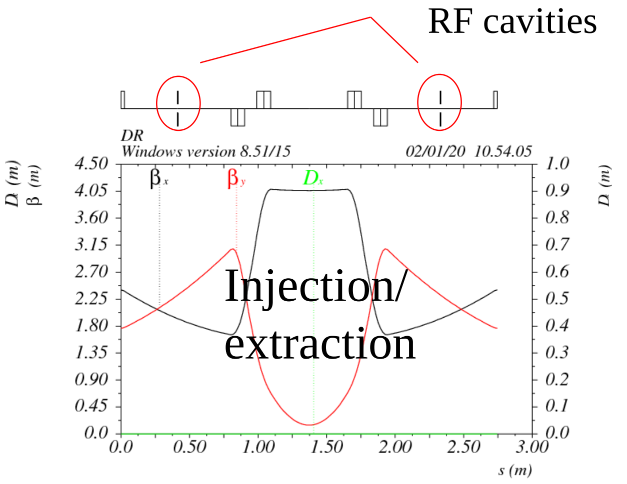
  - 基于超导wiggler的紧凑型阻尼环 *ultra-low emittance during 20 ms*: 2400 → 60 mm.mrad
  - 三级超强束长压缩器 *ultra-short bunch length: 5mm→20μm*
  - 带局部色品校正的强聚焦系统 *20um small beam size at the entrance of plasma accelerator*

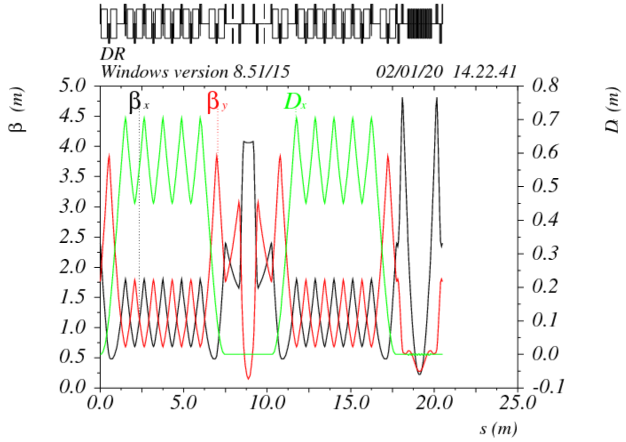
正电子阻尼环设计

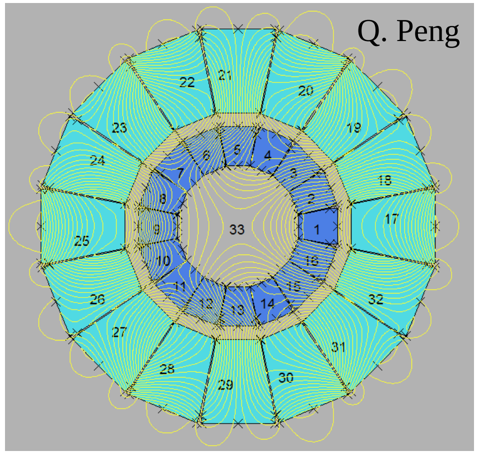
D. Wang, X. N. Wang





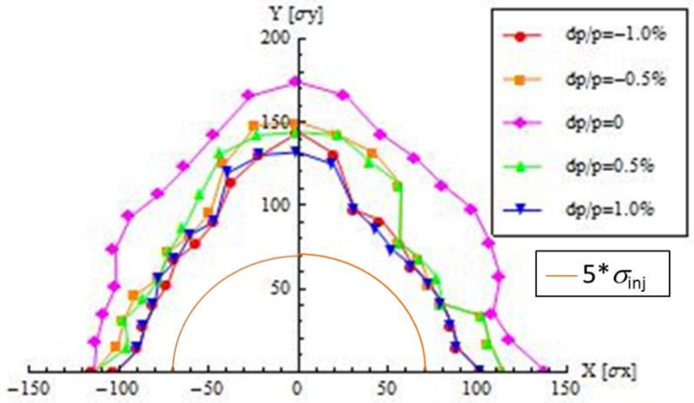






L=8cm, r=2.2cm

Dynamic Aperture



$\nu_x / \nu_y = 3.16/3.21$

Wiggler parameters	
Dipole strength (T)	4.61
Magnetic period (m)	0.176
Total length (m)	1.42
average βx (m)	1.3

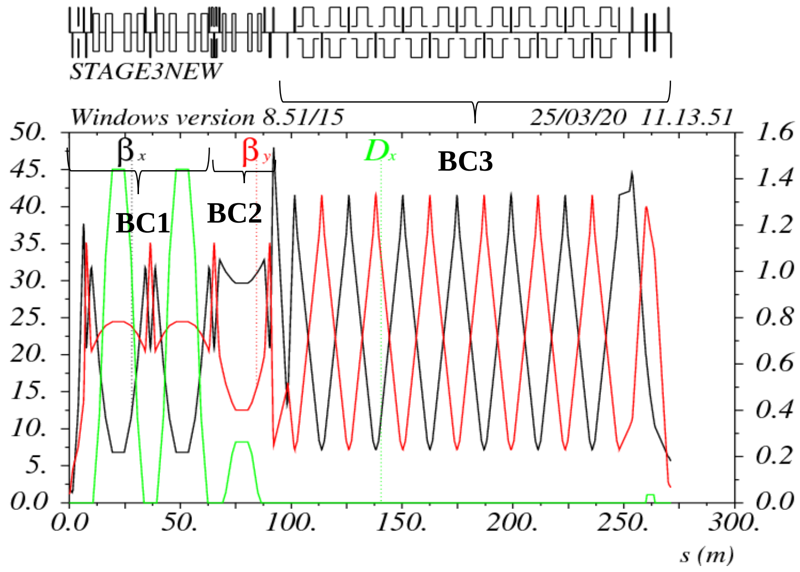
- Combined quadrupole + sextupole (permanent magnet)
- Superconducting wiggler → shorter damping time & smaller equilibrium emittance

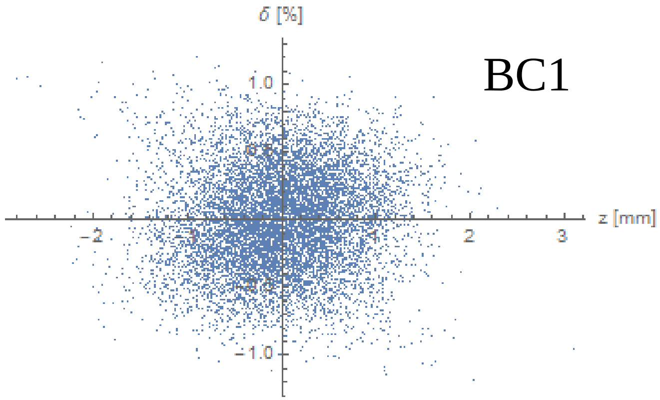
三级束长压缩器设计

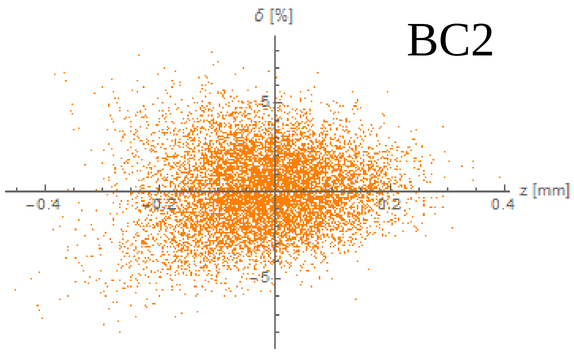
D. Wang, X. H. Cui

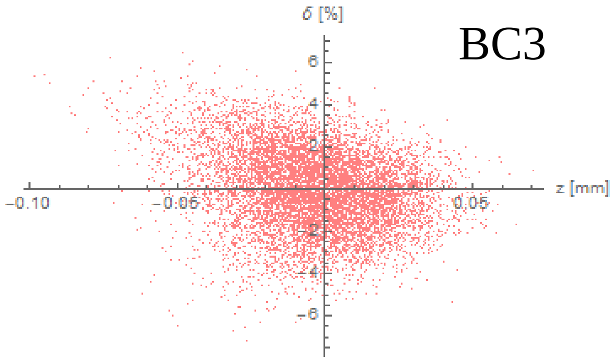
	BCI	BCII	BCIII
Initial energy (MeV)	400	400.1	405
δinj (%)	0.05	0.367	2.17
Initial σz (mm)	4.4	600	100
f_{RF} (GHz)	2.860	5.712	5.712
Voltage(GV)	0.0056	0.12	4.18
Gradient (MV/m)	20	40	40
L (m)	0.28	3	104
ϕ_{RF} (degree)	89	88	61.5
R_{56} (mm)	1200	27.6	5.5
Final energy(MeV)	400.1	405	2400
δext (%)	0.367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





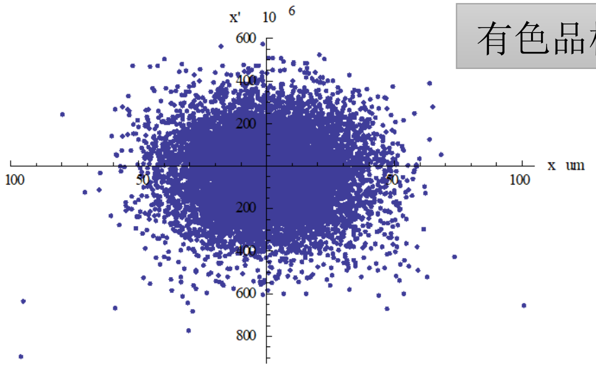


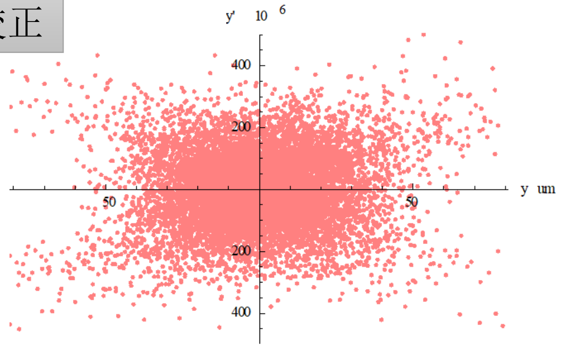


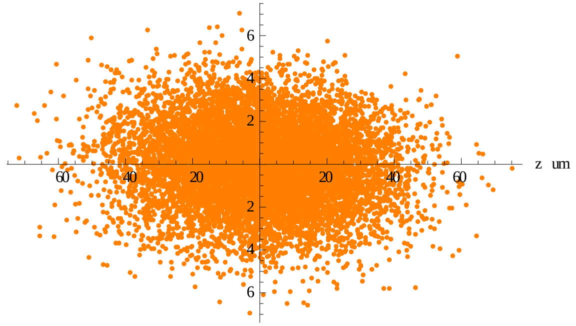
聚焦系统设计

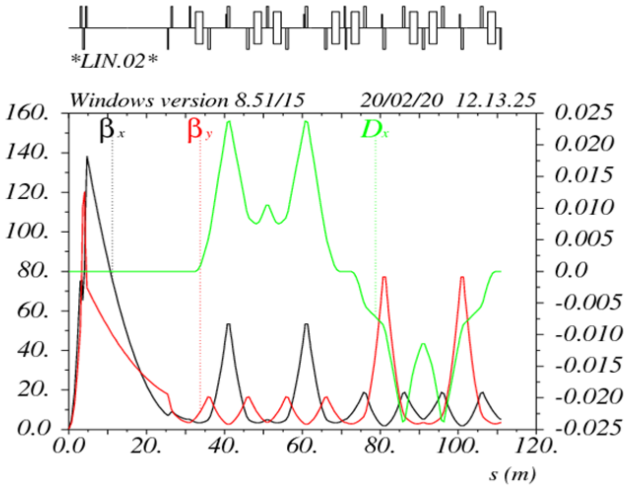
- **Goal**: 20um beam size for horizontal/vertical
- E=2.4GeV, εxn= 15mm·mrad, εyn=10mm·mrad
- L*=3.0m
- βx*=0.12m, βy*=0.18m
- Local chromaticity correction included

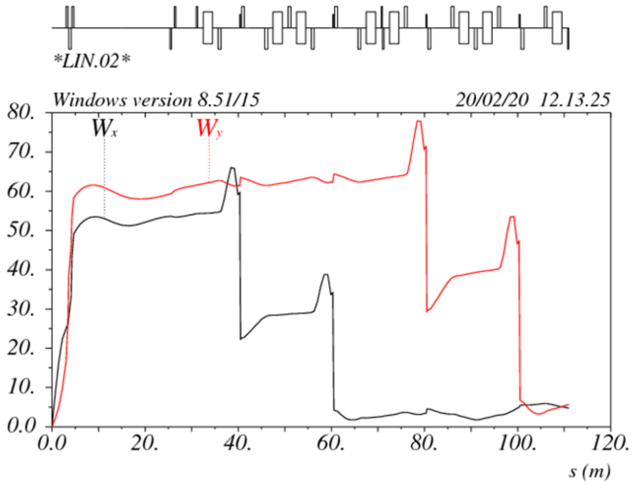
有色品校正





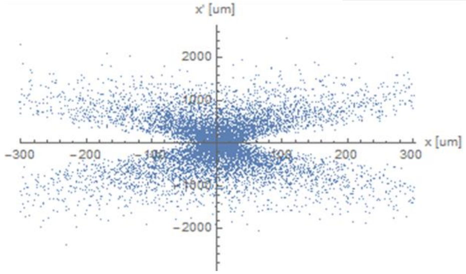


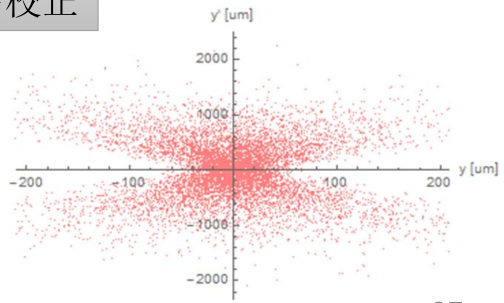




B=87.8Gs, L=2.0m, critical energy=33.6 eV

无色品校正





- 严格控制色品校正段二极铁强度，保证束长20um不增长，同时检查特征能量，保证同步辐射不会对后续plasma加速器有影响。

会议报告

1) CEPC Parameter, Booster and Damping Ring Status，IAS2020，Hong Kong，Jan. 2020
2) Impacts of Detector Stray Field on Booster， CEPC MDI Workshop，Beijing， May. 2020
3) CEPC 加速器概况，第二届粒子物理天问论坛，湖南大学，Aug. 2020
4) CEPC ttbar parameter and booster parameters for high lum Z and ttbar option, CEPC working day, IHEP, Jun. 2020
5) Ground vibration tolerance for CEPC booster，CEPC ground motion meeting，Mar. 2020
6) Positron cooling for CEPC PWFA injector, CEPC PWFA injector meeting, IHEP, Mar. 2020
7) CEPC parameters and booster in TDR, CEPC working day, IHEP, Oct. 2020
8) CEPC booster，CEPC-SPPC international workshop, Shanghai, Oct. 2020.

参与基金项目

- CEPC Physics and key technology R&D (MOST1)
- CEPC key technology R&D (MOST2)
- Accelerator design study for future energy frontier e+e- colliders (CAS-Frontier Key Program)
- Key accelerator physics for future large circular colliders (NSFC-general)
- Beam physics for future circular e+e- colliders (NSFC-general)
- CEPC Plasma Wake Field Acceleration injector R&D (CAS center for excellence)

文章发表

1) Dou Wang, et al., "Design and beam dynamics of the CEPC booster", International Journal of Modern Physics A, Vol. 35 (2020) 2041007.
2) Dou Wang, et al., "Design and beam dynamics of CEPC damping ring system", IAS white paper, Hong Kong, 2020.
3) Dou Wang, et al., "Design study of CEPC lower emittance booster", IAS white paper, Hong Kong, 2020.
4) Y. Chen, D. Wang, et al., "Analytical expression development for eddy field and the beam dynamics effect on CEPC booster", IAS white paper, Hong Kong, 2020.
5) Yuan Zhang, Na Wang, Chuntao Lin, Dou Wang, et al., "Self-consistent simulation of beam-beam interaction in future e+e- circular colliders including beamstrahlung and longitudinal coupling impedance", PRSTAB, 2020.
6) Dou Wang, et al., "Impacts of Detector Stray Field on Booster", IHEP AP note, ACC-AP-NOTE-2020-001, June 2020.

谢谢大家！

多批评指正！