Alternatives injection design for FCCee injector linac

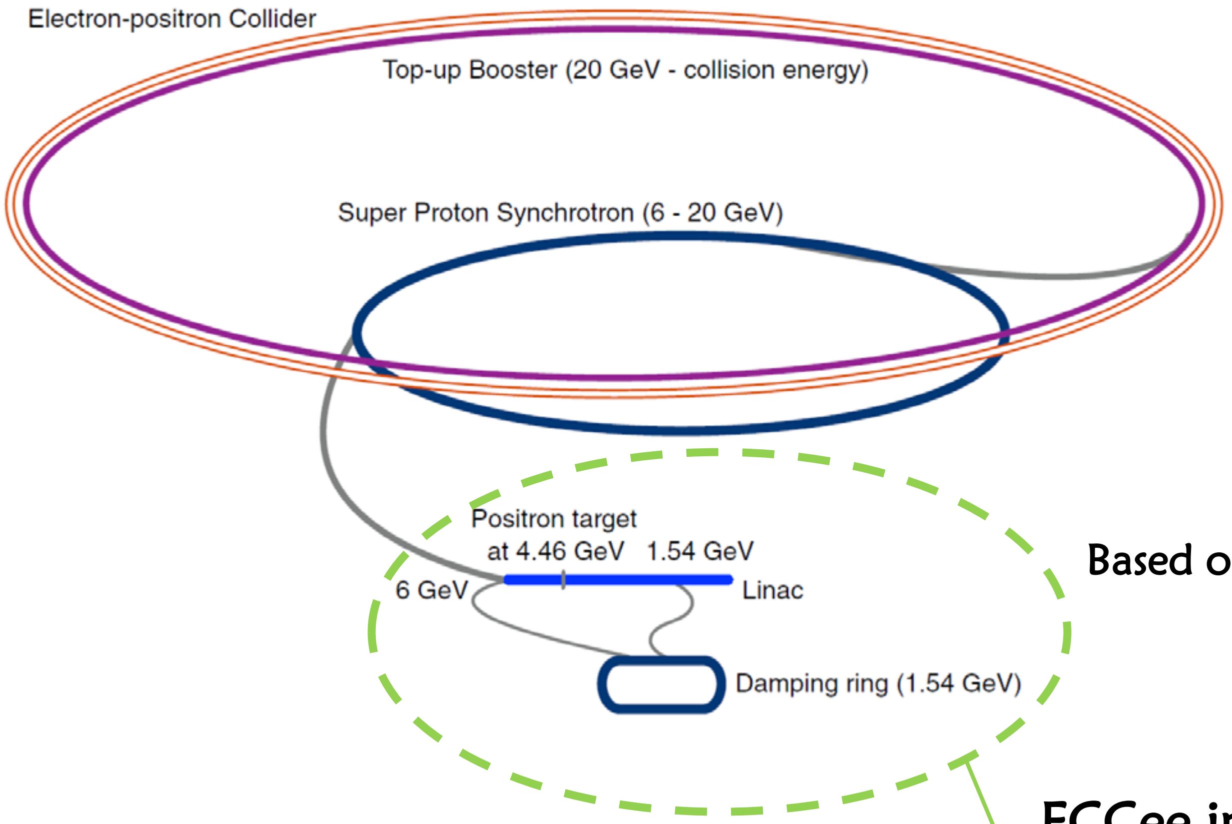
B. Bai, A. Faus-Golfe, Y. Han, I. Chaikovska, Z. Zhou, Y. Chi

in collaboration with F. Zimmermann and K. Oide

26/10/2020

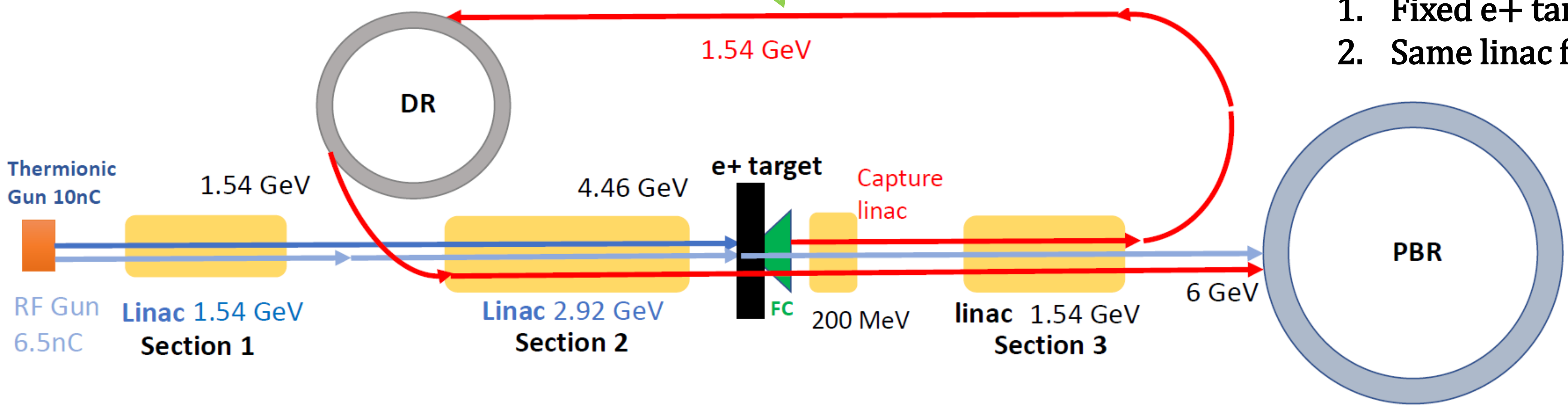
CEPC workshop

FCCee injector complex



Based on SuperKEKb (common linac for e+/e-)

FCCee injector linac baseline



Two drawbacks:

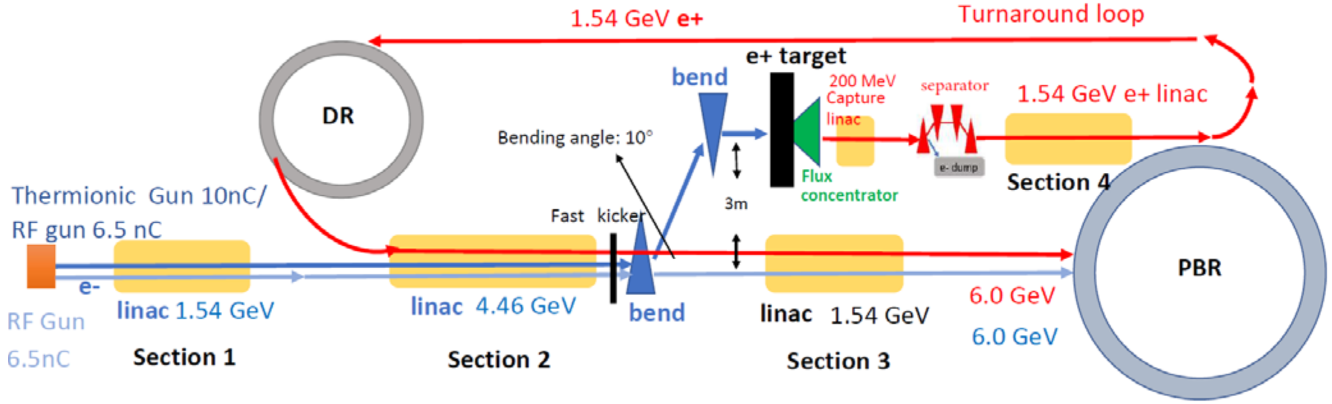
1. Fixed e+ target: flexibility
2. Same linac for e+/e-: efficiency

Colliders / Parameters	SLC	LEP	SuperKEKB	CLIC	ILC	CEPC	FCCee
Incident e- beam energy [GeV]	33	0.2	3.5	5	125/250	4	4.46
e-/bunch[10^{10}]	3-5	0.5-30	6.25	1.1	2	6.25	4.2 (or 6.25)
Bunch/pulse	1	1	2	312	1312	1	2
Repetition rate [Hz]	120	100	50	50	5	100	200
Incident beam power [kW]	~ 20	1	3.3	140	~ 60/43(photon)	4	12
Beam size @ target [mm]	0.6-0.8	< 2	> 0.7	2.5	1.72/0.5(photon)	0.5	0.5-1
Target scheme	convention	convention	convention	hybrid	convention (polarization)	convention	convention (/hybrid)
Target thickness [mm]	21	7	14	1.4+10	14.8/7	15	16(/1.4+12)
Target mobility	moving	fixed	fixed	moving	moving	moving	moving
Deposited power [kW]	4.4	0.1	0.6	~ 11	~5.4/2.3	0.784	1.5-2.6
Capture system	AMD*	QWT**	AMD	AMD	QWT	AMD	AMD
Magnetic field change [T]	6.8→0.5	1→0.3	4.5→0.4	6→0.5	5→0.5	6→0.5	7→0.7
Capture linac frequency [GHz]	2.856	2.999	2.856	1.999	1.3	2.856	1.999/2.856
DR energy [GeV]	1.15	0.5	1.1	2.86	5	1.1	1.54
e+ yield @ injector exit	1.2 (@ DR)	0.003	0.4	0.7	1.5 (@ DR)	⩾ 0.3	⩾ 0.7

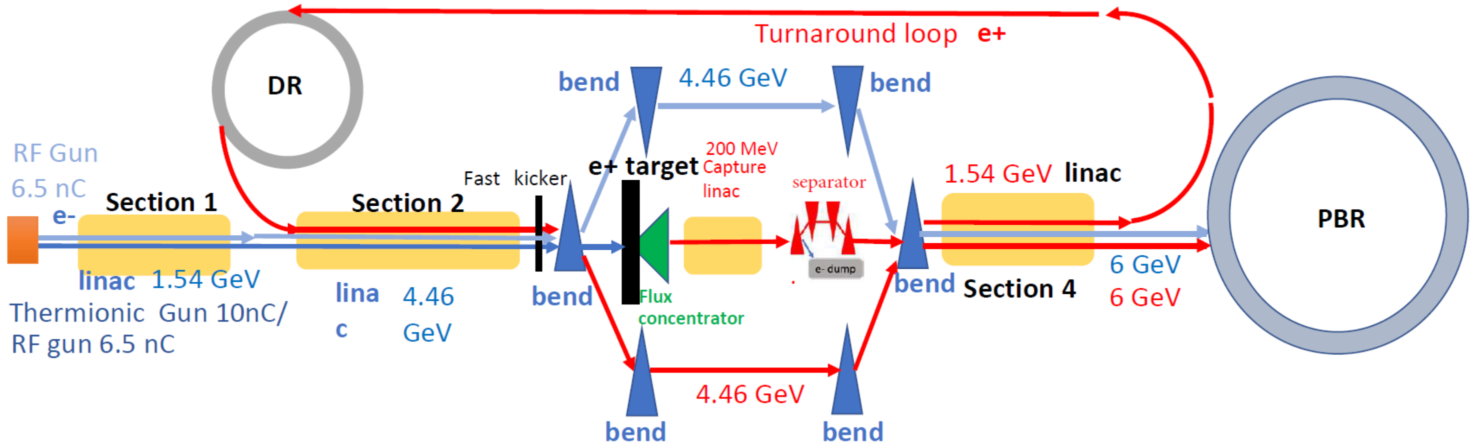
* Adiabatic Matching Device

** Quarter Wave Transformer

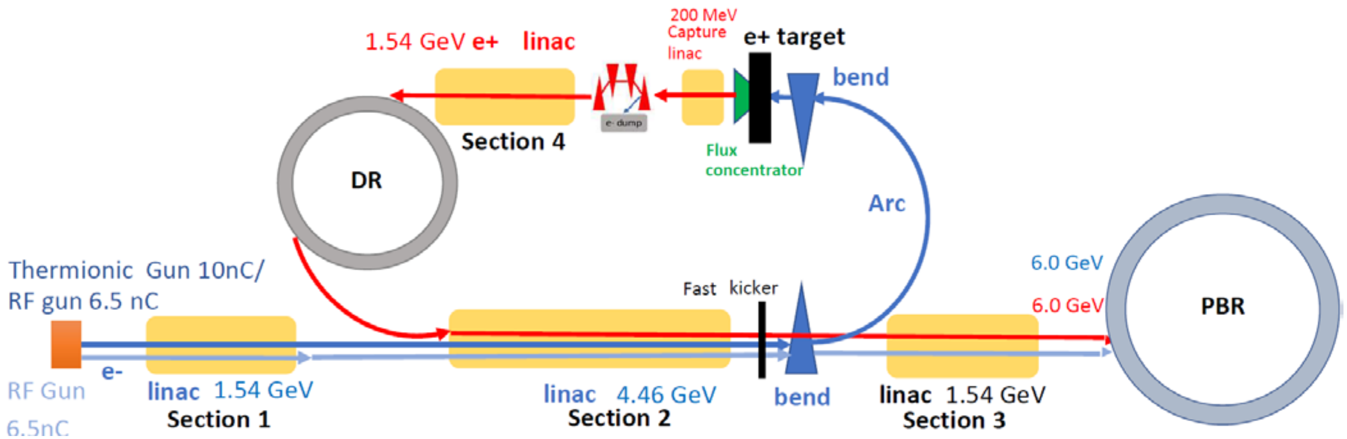
Three different schemes – bypass options



1. Dogleg scheme

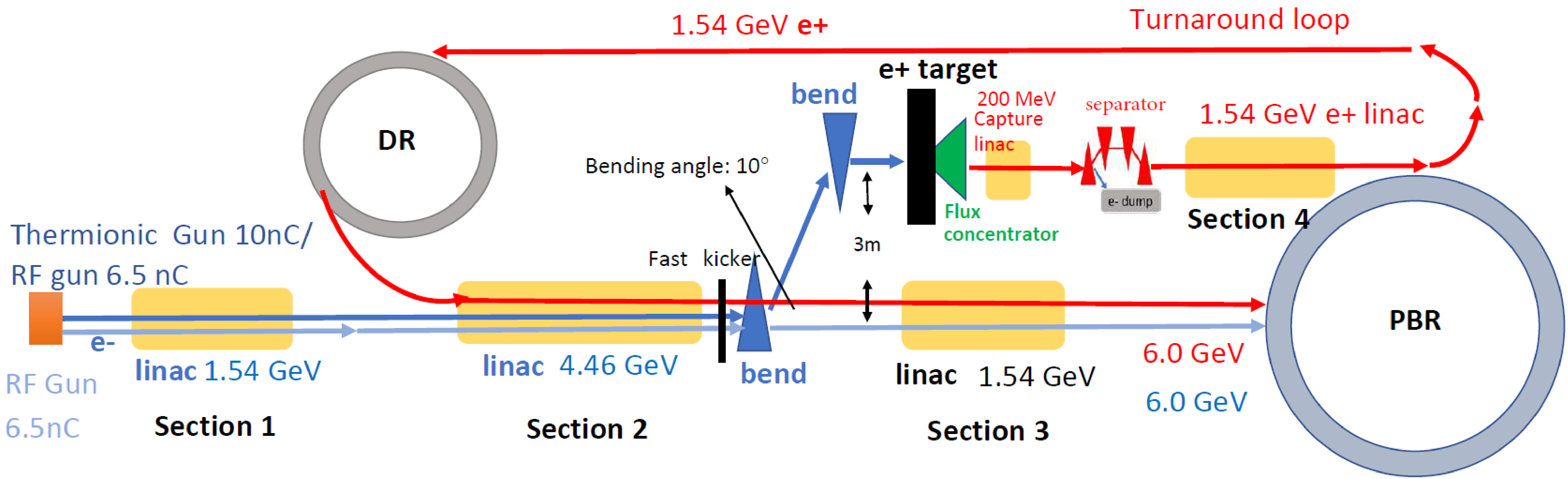


2. Chicane scheme



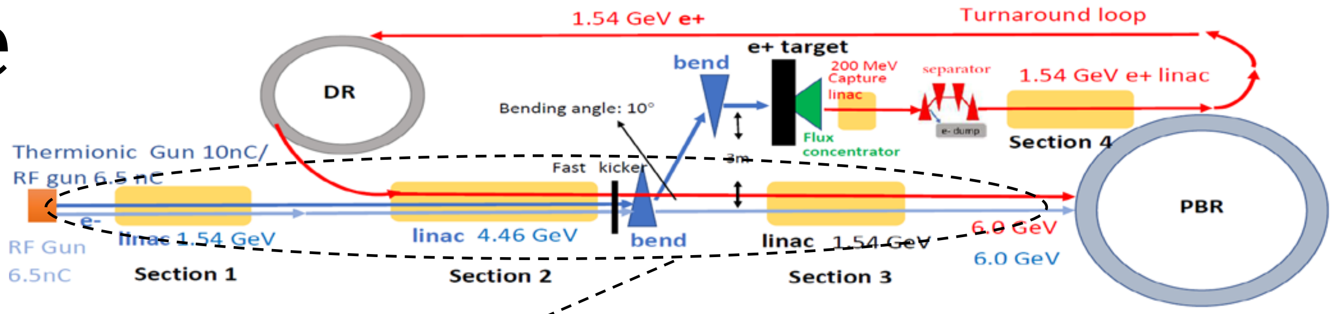
3. Arc scheme

1. Dogleg scheme



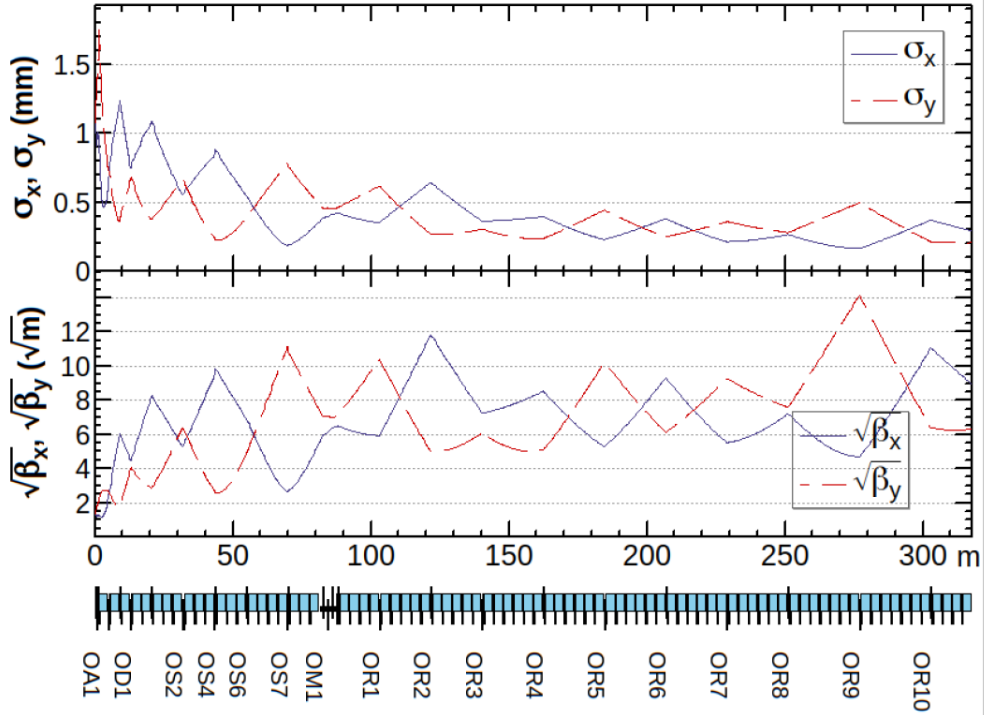
1. Dogleg scheme

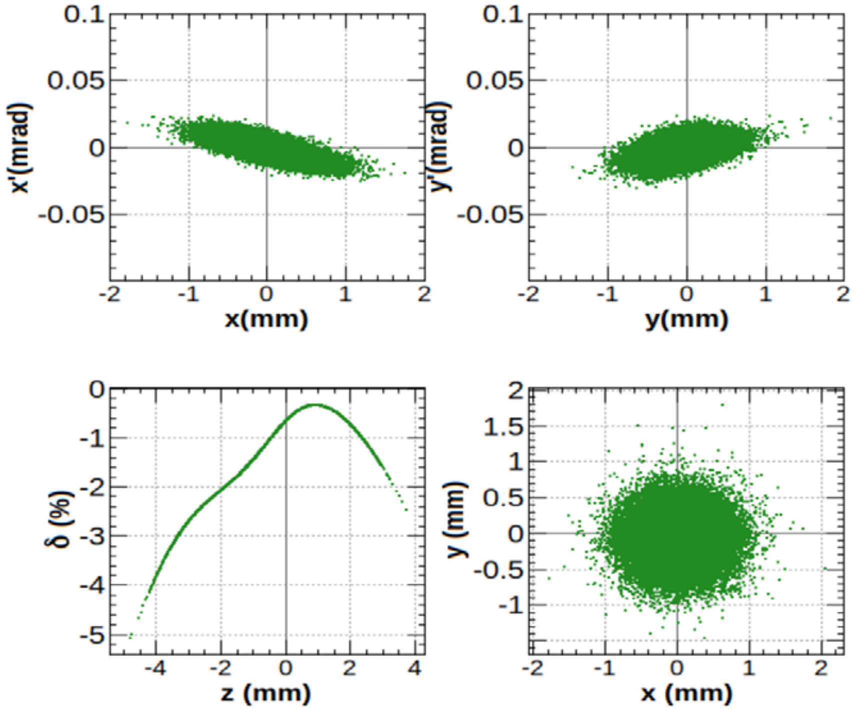
e- beam



Code: SAD

6GeV e- linac





Output:

e-

S band linac, 25 MV/m

Length: ~320 m

Q: 3.5 nC (2.2×10^{10}) per bunch

E: 6 GeV;

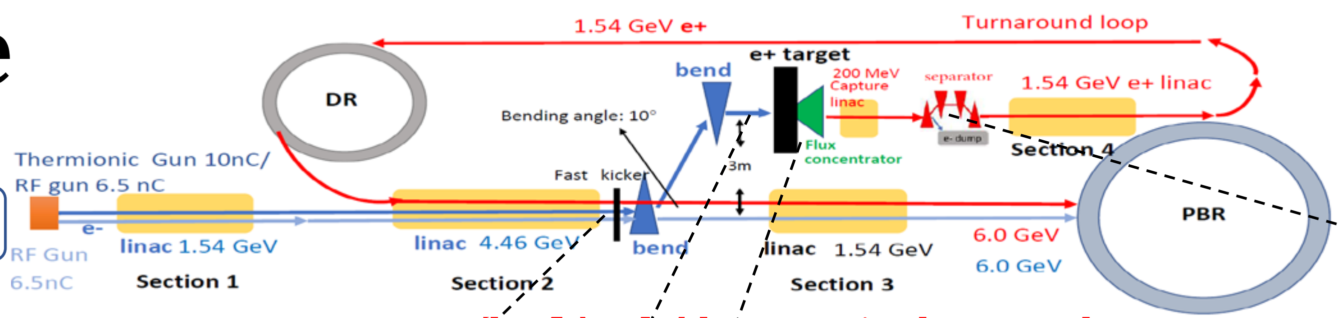
$\frac{\delta E}{E}$: **0.6%;**

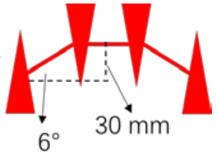
σ_z : 1mm;

$\varepsilon_{x,y}$ = 1.2 nm (normalized 13 μm);

1. Dogleg scheme

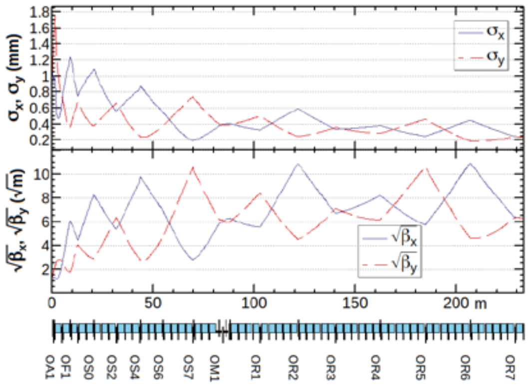
e+ beam

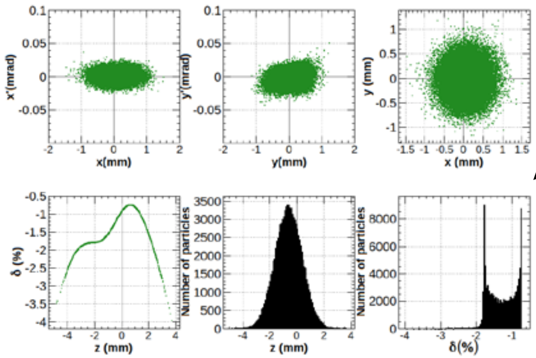




Code: SAD

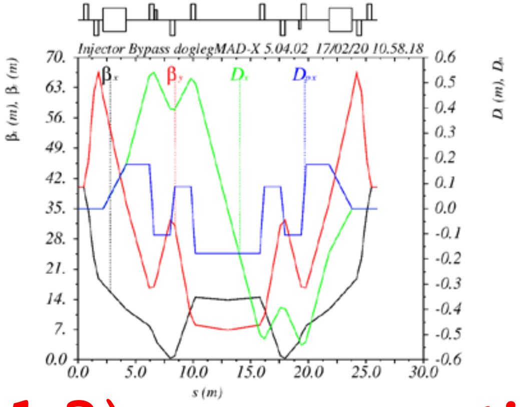
1.1) 4.46GeV e- linac

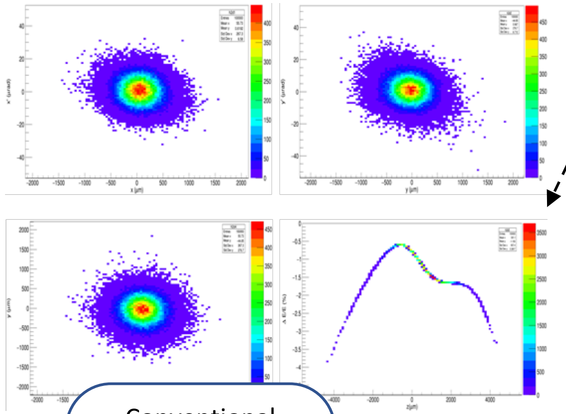




1.2) dogleg bypass

Code: MADX + PLACET



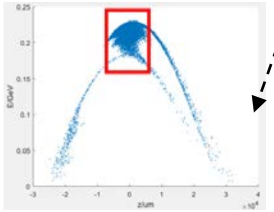


1.3) e+ generation

Results from Dr. Yanliang Han

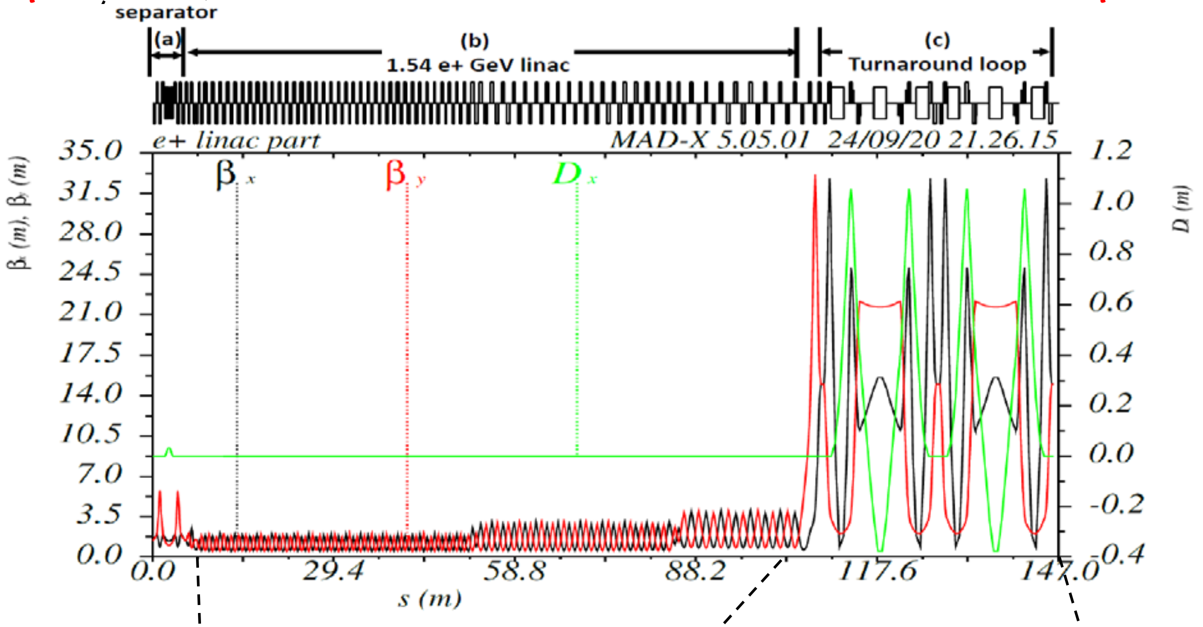
Accelerating mode /decelerating mode
+ Conventional target /hybrid target

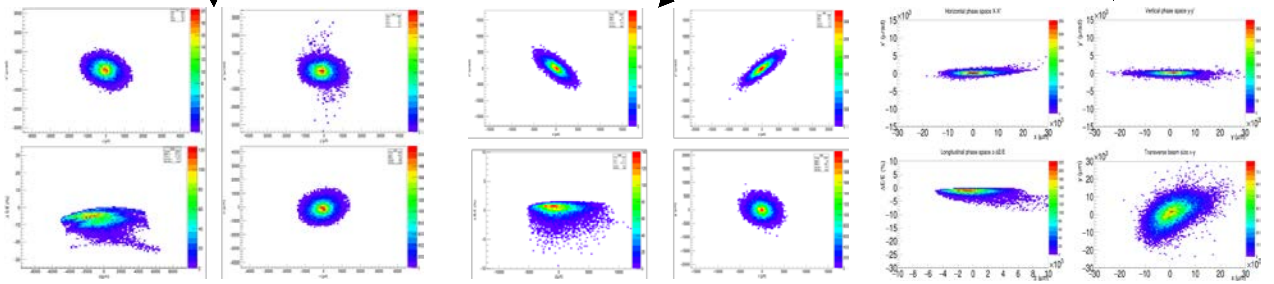
Conventional target
+
deaccelerating mode
Positron yield:
2.3



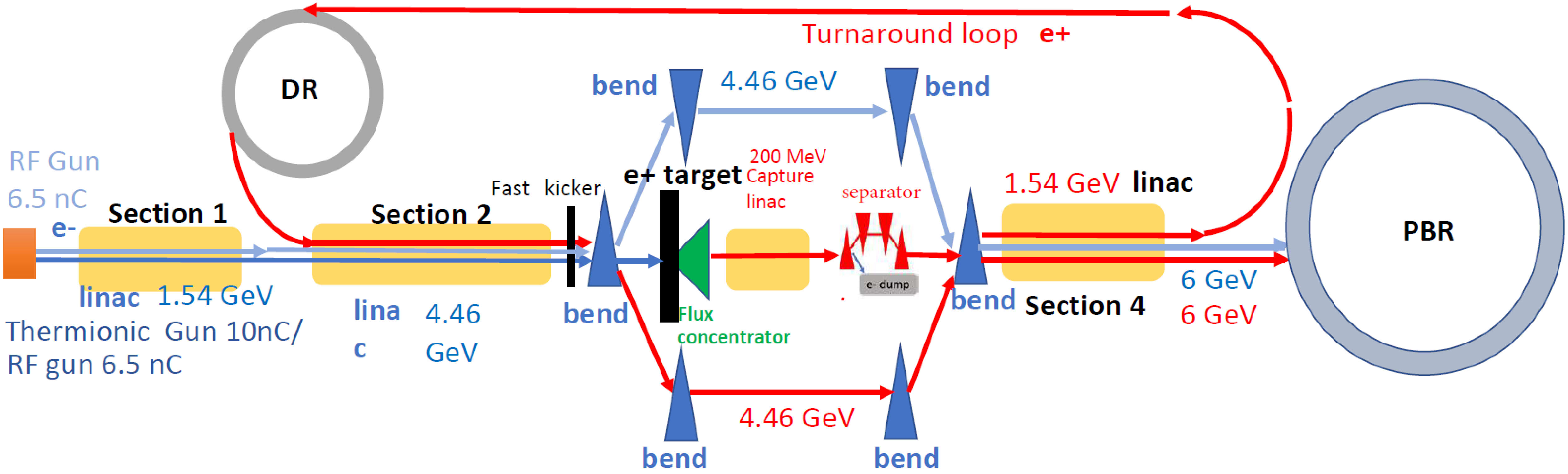
1.4) After e+ target:

separator chicane, 1.54 GeV e+ linac, turnaround loop



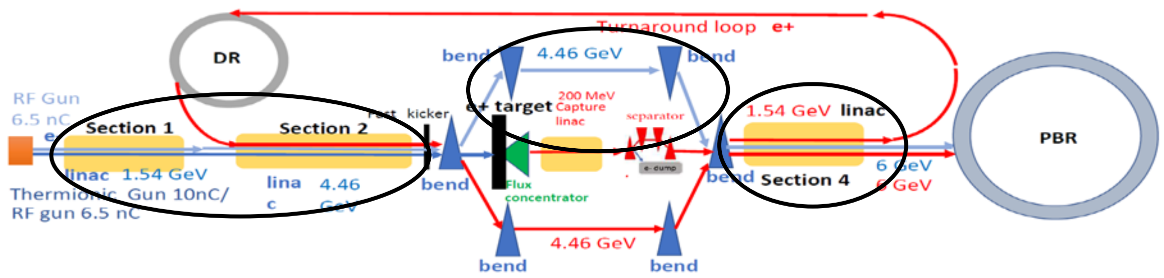


2. Chicane scheme



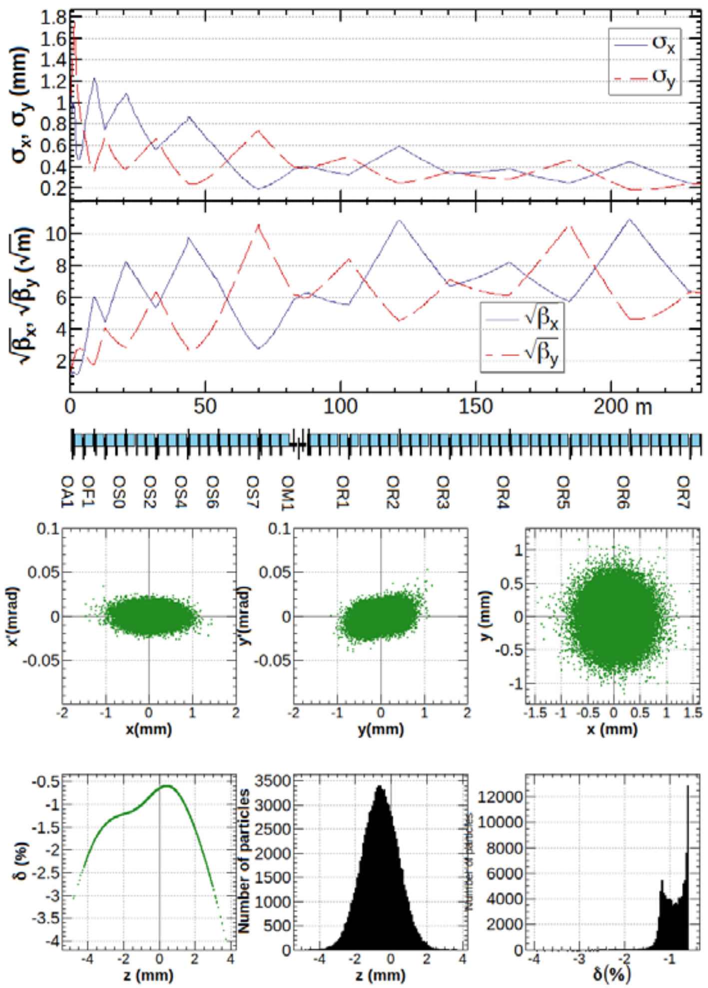
2. Chicane scheme

e- beam



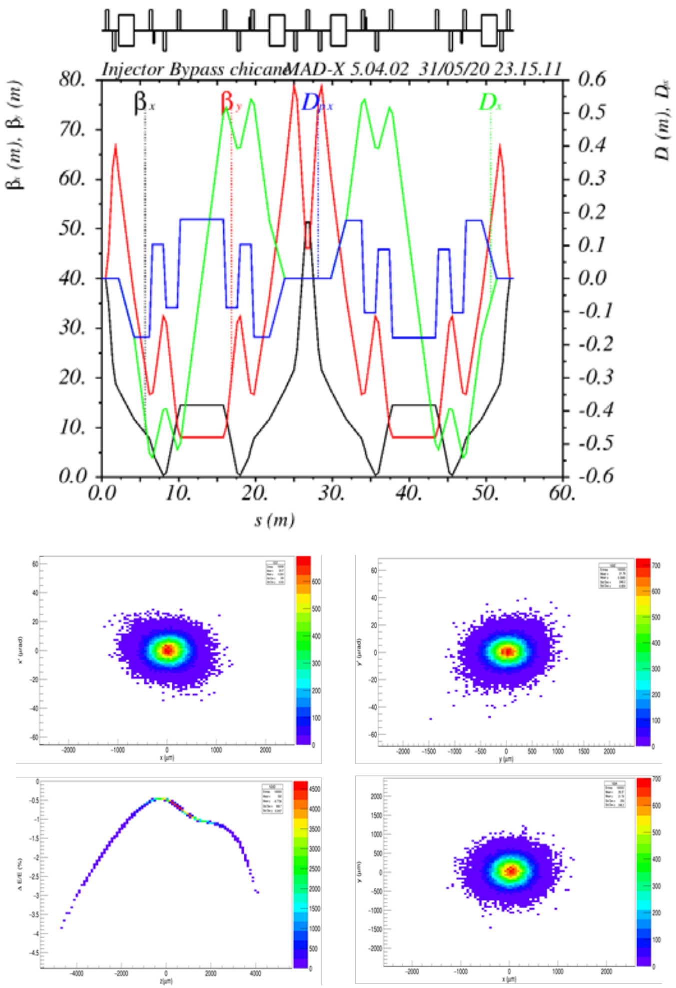
2.1) 4.46GeV e- linac

Code: SAD

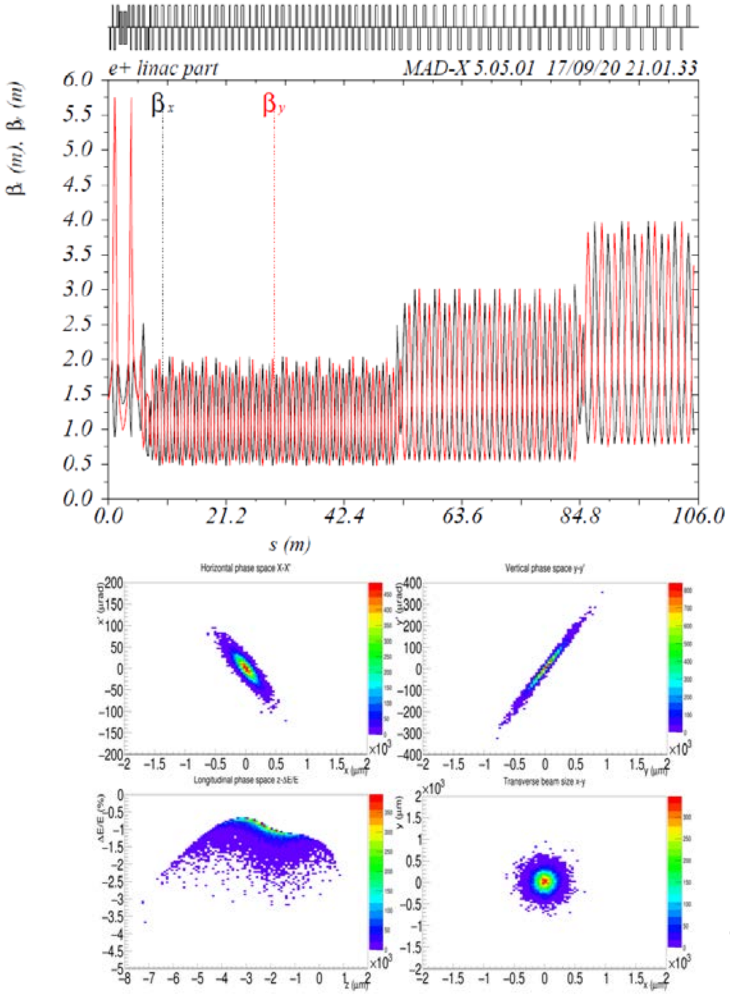


2.2) chicane bypass

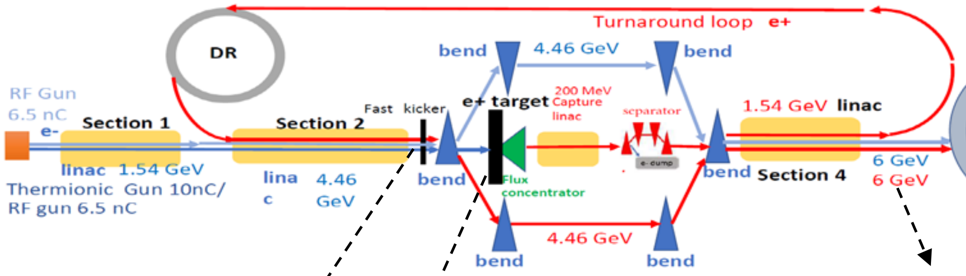
Code: MADX + PLACET

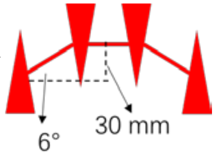


2.3) 1.54 GeV e+/e- linac



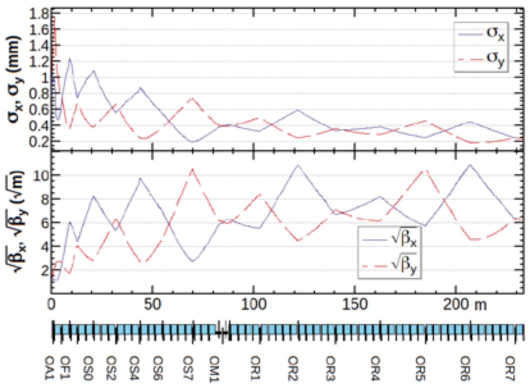
2. Chicane scheme
e+ beam

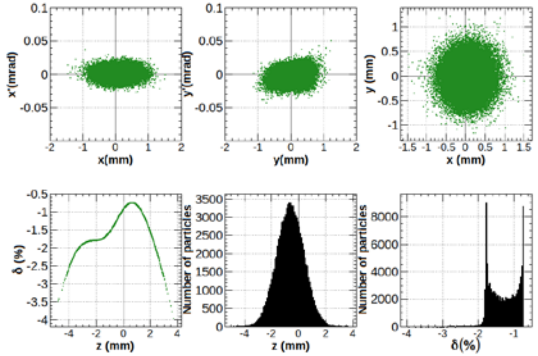




2.4) 4.46GeV e- linac

Code: SAD



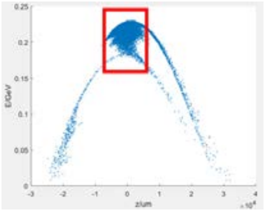


2.5) e+ generation

Results from Dr. Yanliang Han

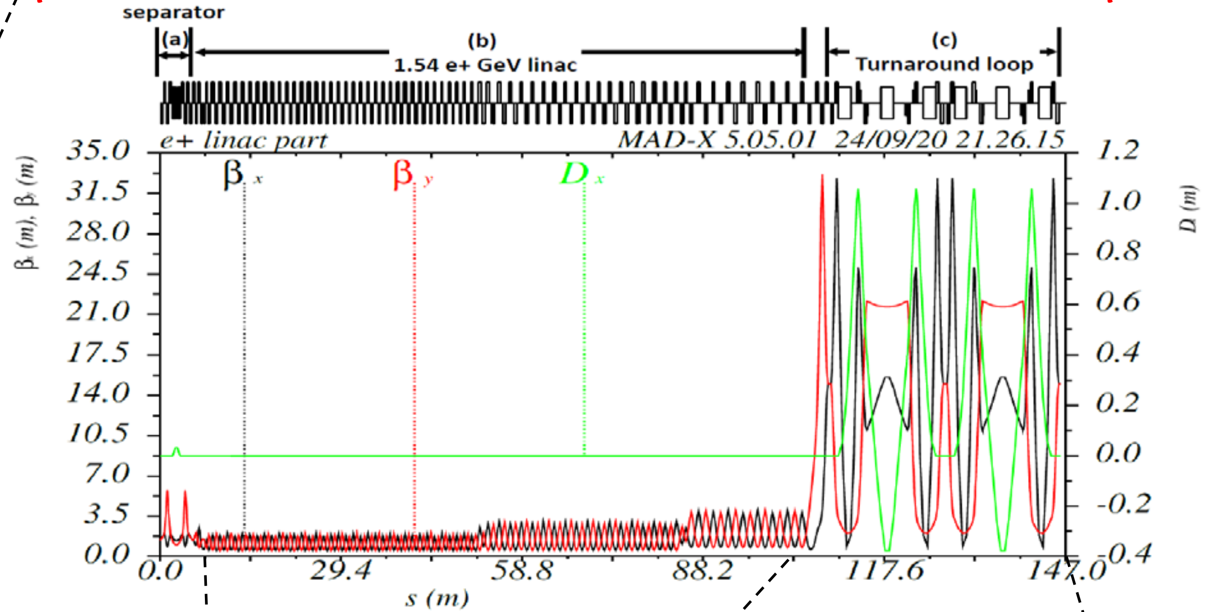
Accelerating mode /decelerating mode
+ Conventional target /hybrid target

Conventional target
+
deaccelerating mode
Positron yield:
2.3

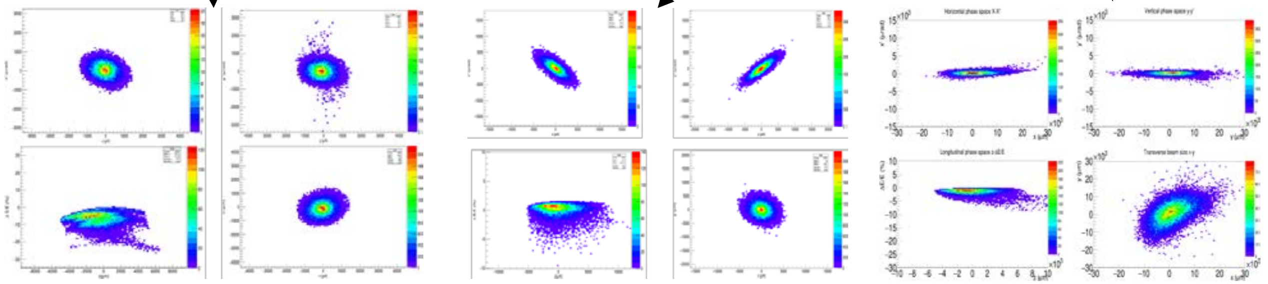


2.6) After e+ target:

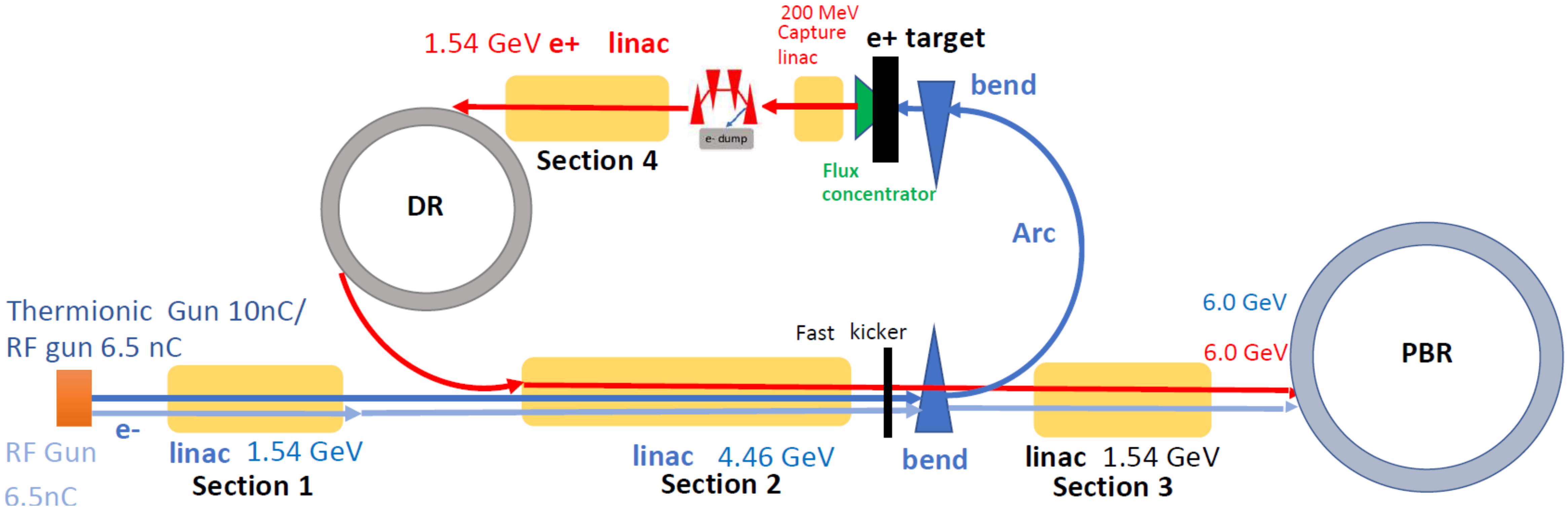
separator chicane, 1.54 GeV e+ linac, turnaround loop



Code: MADX + PLACET

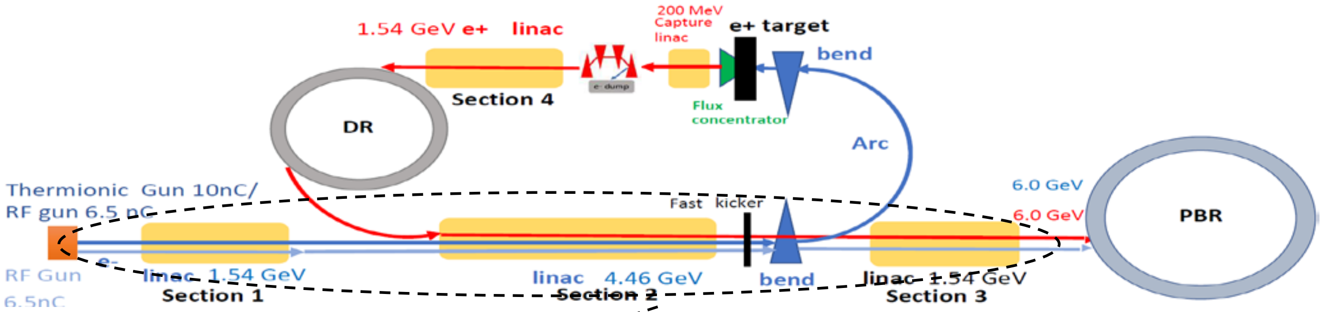


3. Arc scheme

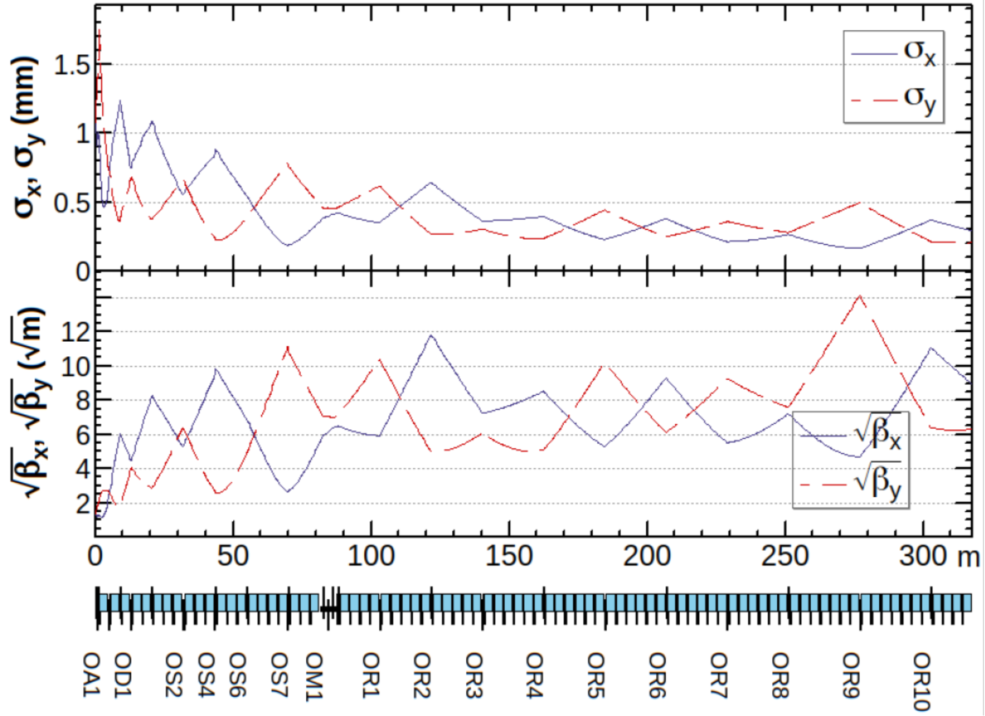


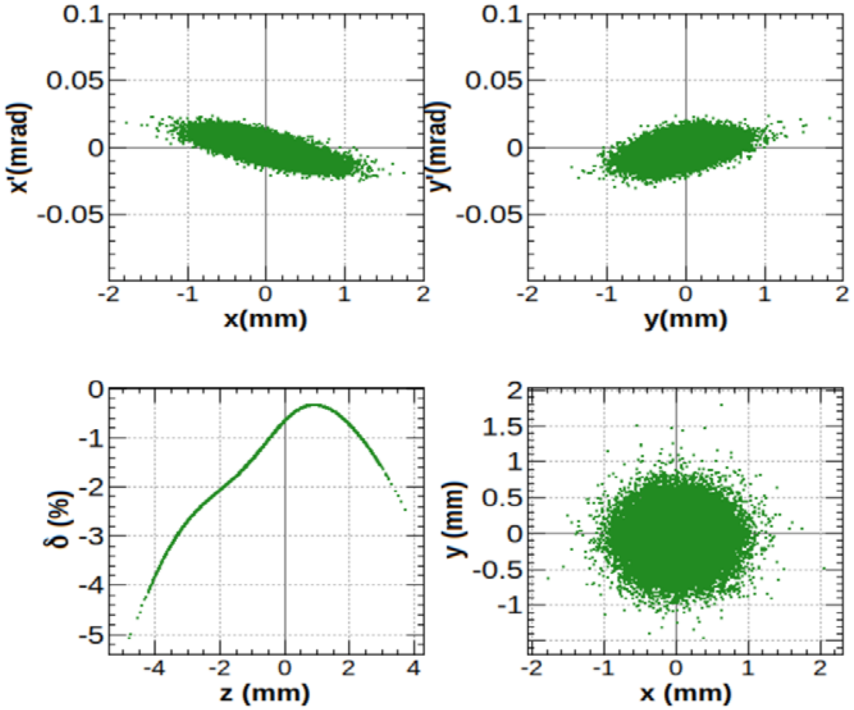
1.54 GeV e+ linac
200 MeV
Capture
linac
e+ target
bend
e- dump
Section 4
Flux
concentrator
DR
Arc
Thermionic Gun 10nC/
RF gun 6.5 nC
Fast kicker
6.0 GeV
6.0 GeV
PBR
e-
RF Gun
6.5nC
linac 1.54 GeV
Section 1
linac 4.46 GeV
Section 2
bend
linac 1.54 GeV
Section 3

3. Arc scheme
e- beam



6GeV e- linac





Output:

e-

S band linac, 25 MV/m

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E: 6 GeV;

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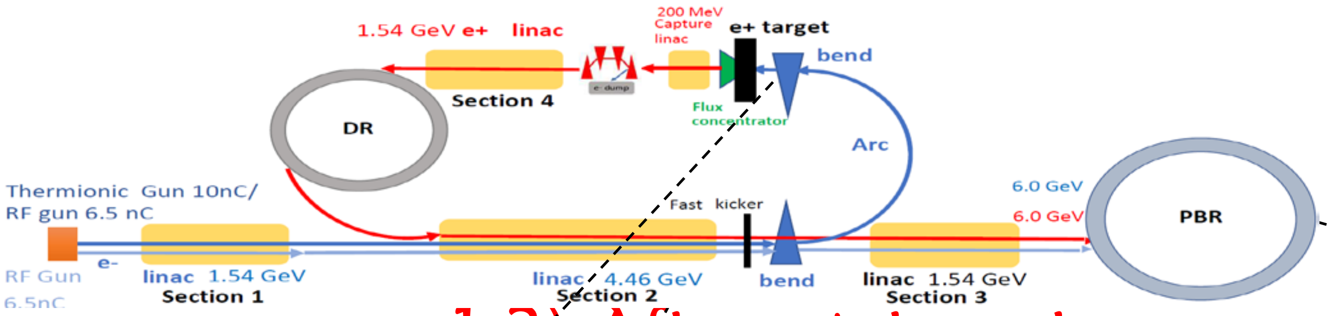
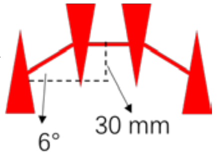
σ_z : 1mm;

$\varepsilon_{x,y} = 1.2$ nm (normalized 13 μm);

3. Arc scheme

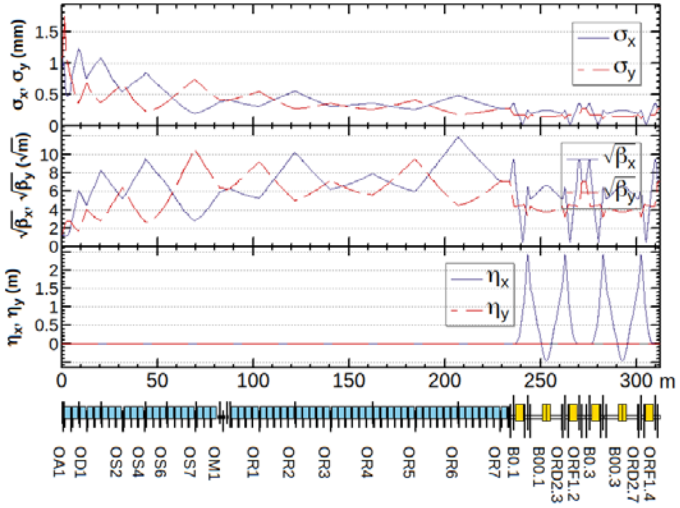
e+ beam

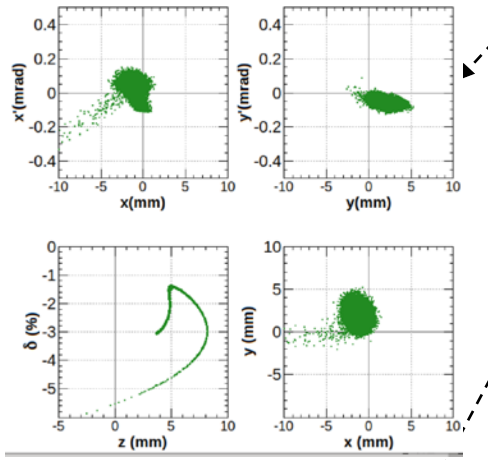




1.1) before e+ target

Code: SAD





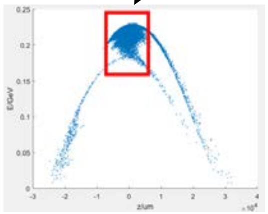
10 nC case

1.2) e+ generation

Results from Dr. Yanliang Han

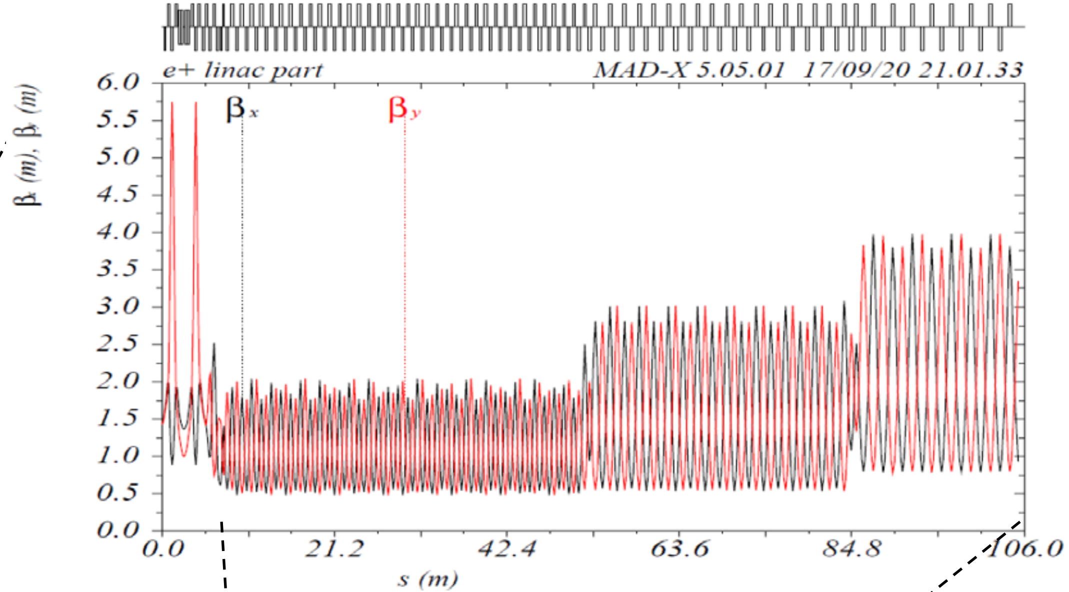
Accelerating mode /decelerating mode
+ Conventional target /hybrid target

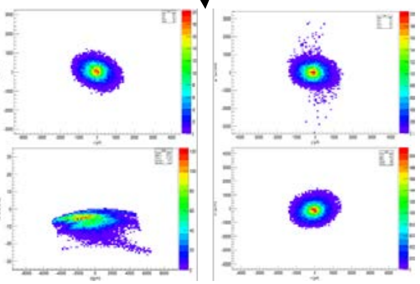
Conventional target
+
deaccelerating mode
Positron yield:
2.3

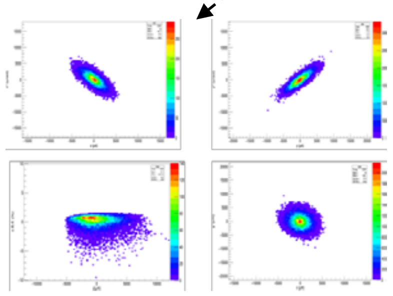


1.3) After e+ target:

separator chicane, 1.54 GeV e+ linac







4. Results

Dogleg scheme	Simple bypass (2 bends) + Additional 1.54 GeV linac (section 4) + 1.54 GeV e+ turnaround loop (arc)	High efficiency
Chicane scheme	Complex bypass (4 bends) + 1.54 GeV e+ turnaround loop (arc)	Less cost
Arc scheme	Most complex bypass (6 bends) + 4.46 GeV e- arc Additional 1.54 GeV linac (section 4)	Simple system

The three schemes design can meet the requirement of the Z mode of FCCee.
(e+ yield is about 1.2, see backup slides)

Other new designs are being proposed by our team…
Our design can work as a scale and preliminary study for future proposals.

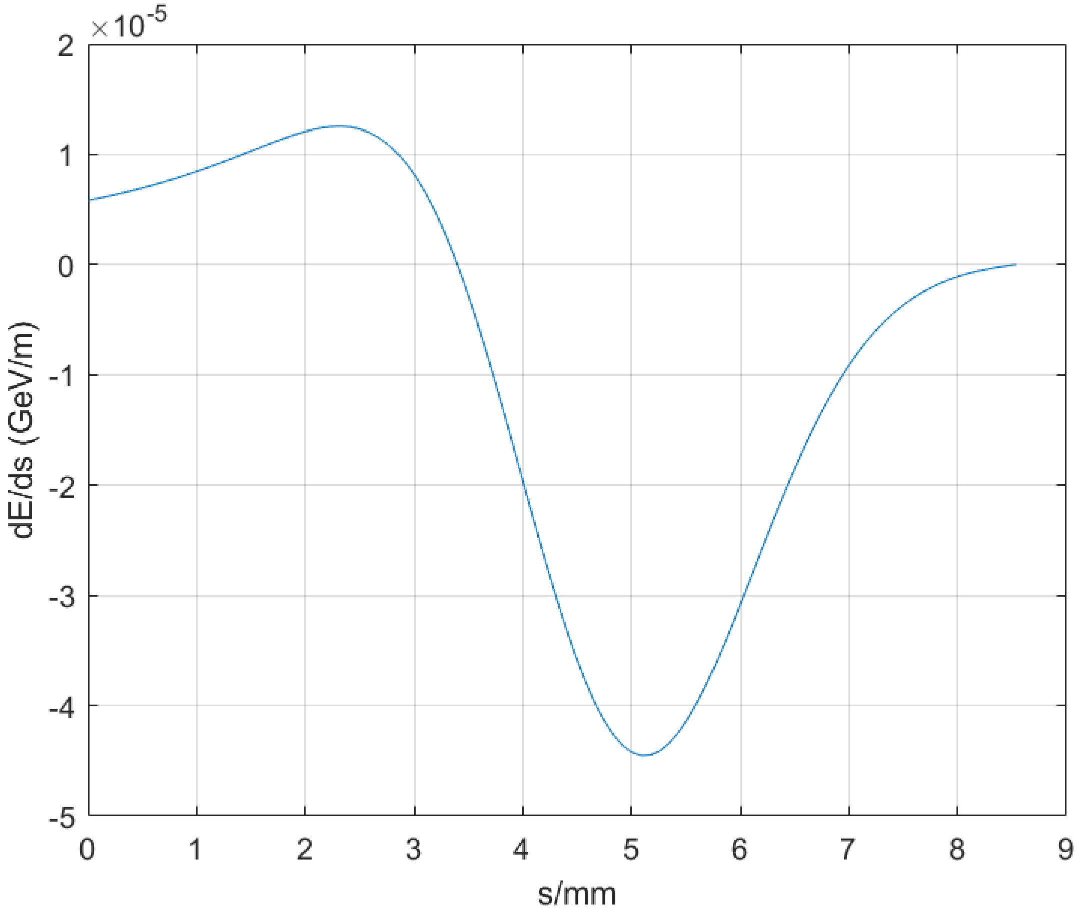
Realistic bunch properties will be studied in future
with the experiments of test facilities for both species (e+/e-) injection.

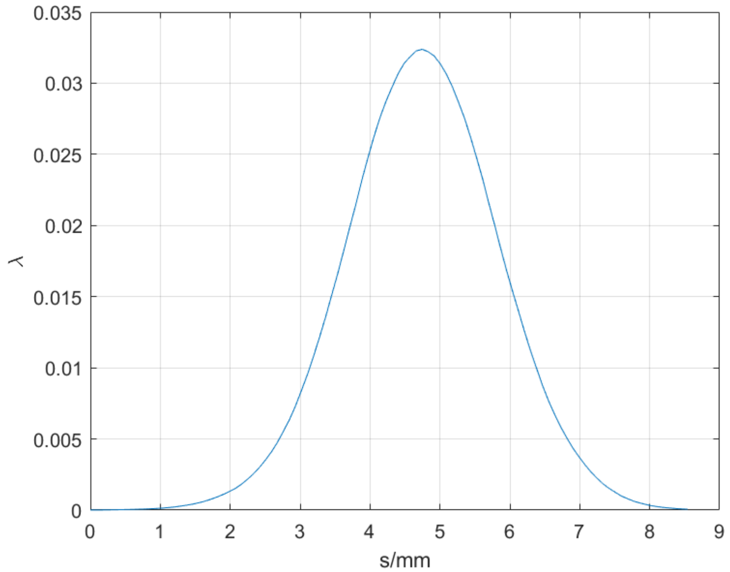
Thanks!

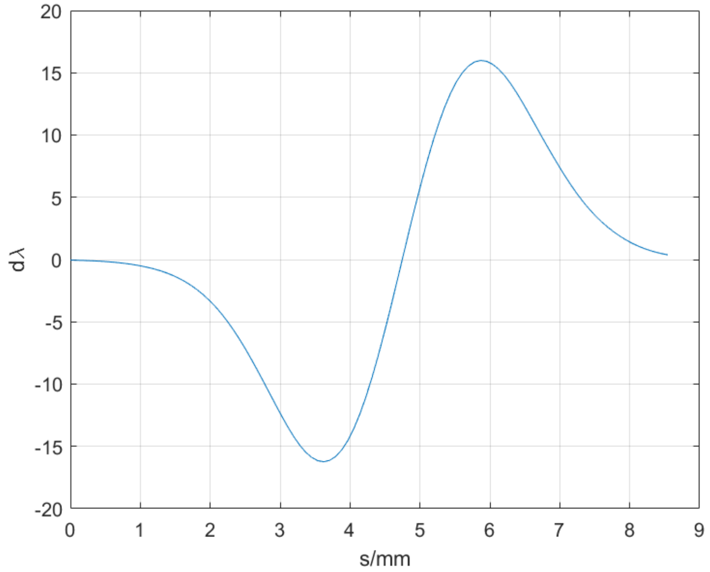
Backups

CSR study – dogleg bypass
5nC e- (6.5nC RF gun)

S: bunch length







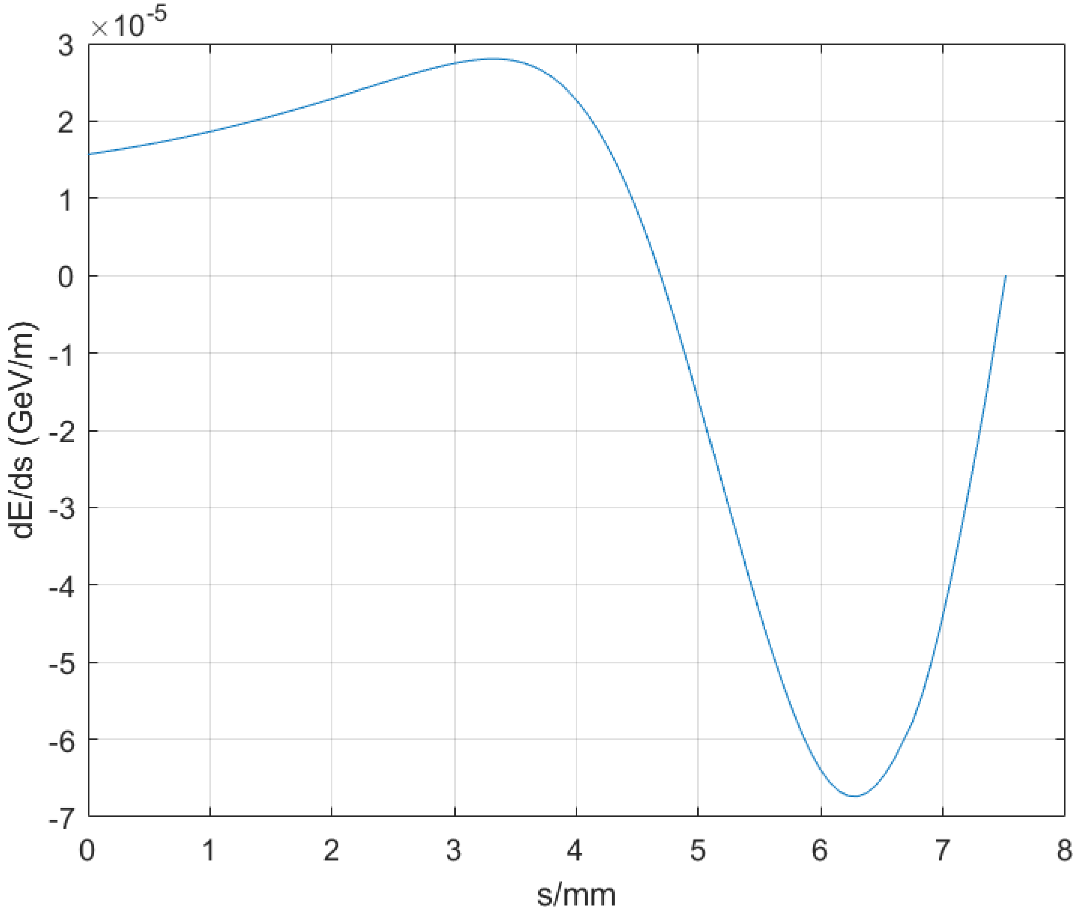
Line charge distribution,

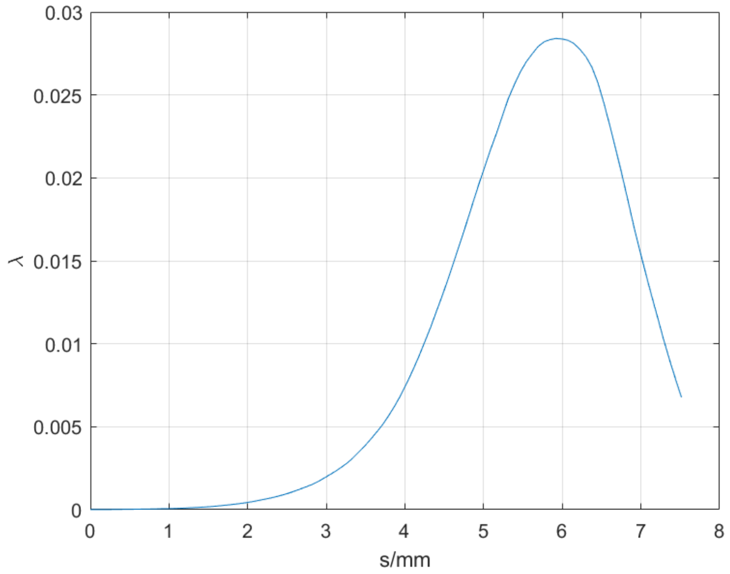
Normalized line density **λ**

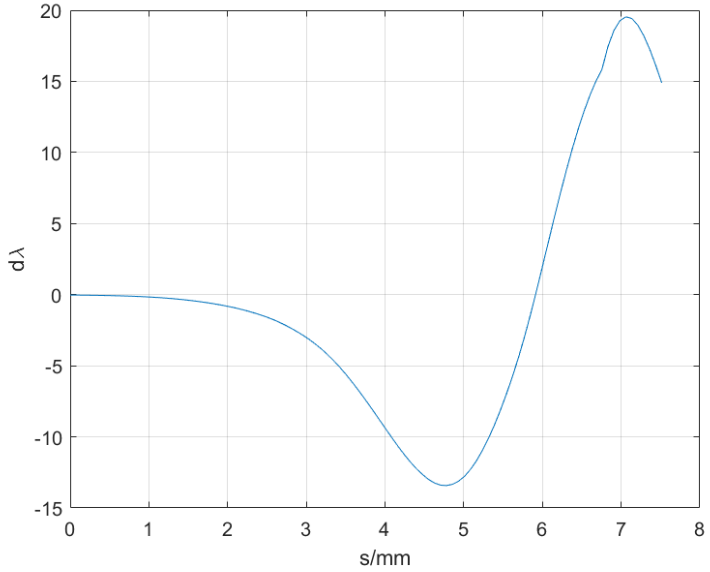
one-dimensional charge density ρ=Qλs

CSR study – dogleg bypass
8.44nC e- (10nC thermal gun)

S: bunch length







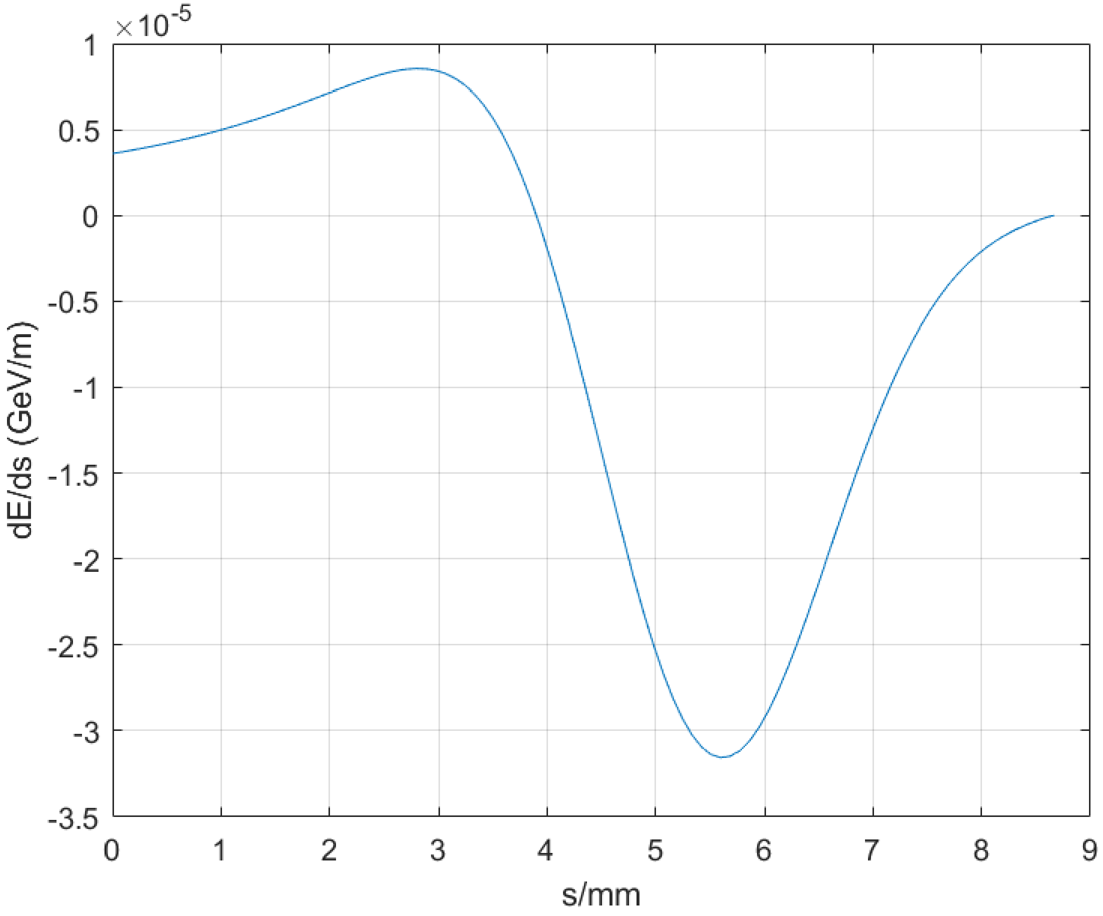
Line charge distribution,

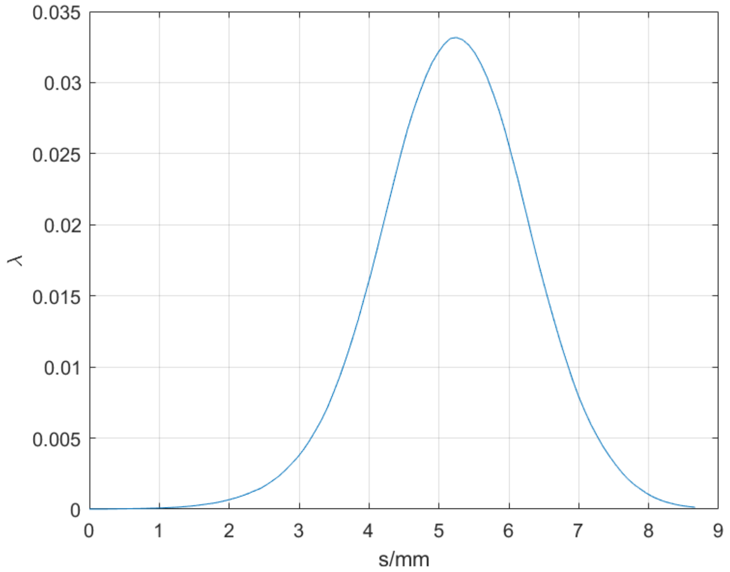
Normalized line density **λ**

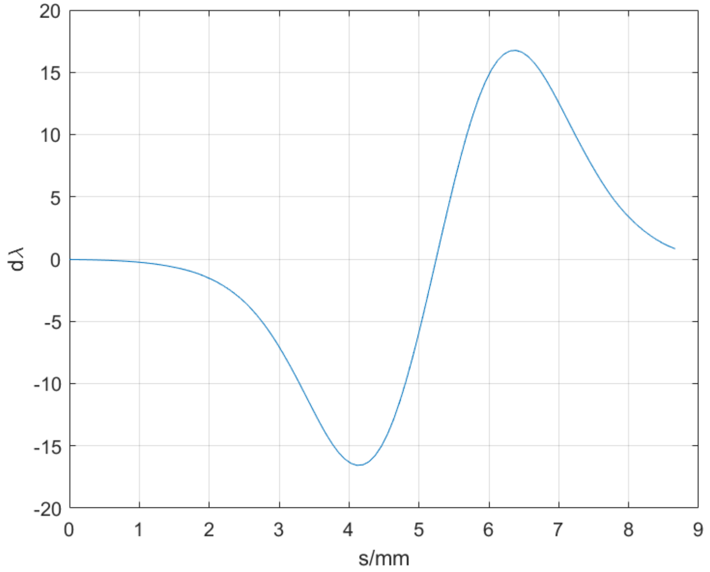
one-dimensional charge density $\rho = Q\lambda s$

CSR study – chicane bypass 3.5nC e- (6.5nC RF gun)

S: bunch length







Line charge distribution,

Normalized line density **λ**

one-dimensional charge density ρ=Qλs

1.54 GeV e+ linac FODO cell

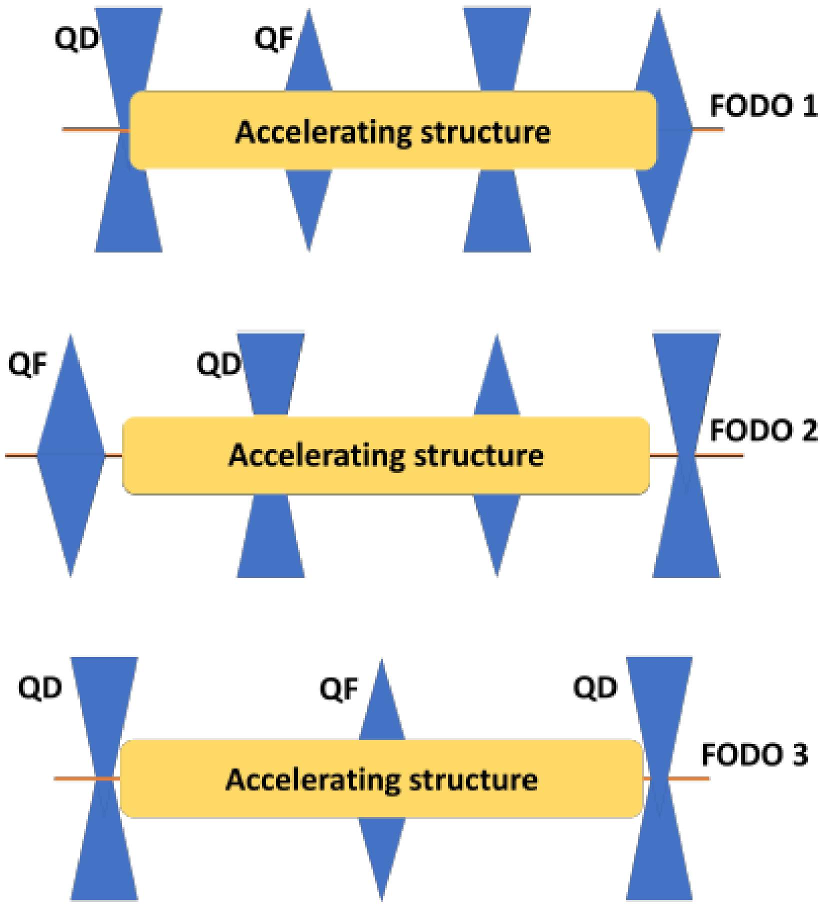


Table 3: Parameters of the three different FODO cells

Section	L_Q (m)	k (m^{-2})	β_{max}(m)	L_{Cell} (m)	N_{cell}	E_{input} (GeV)	E_{output} (GeV)
1	0.3	±8.20	2	1.2	36	0.214	0.694
2	0.4	±4.69	3	1.8	17	0.694	1.254
3	0.4	±3.22	4	2.4	8	1.254	1.564

12 LAS + 28 normal S band

LAS	
Acceleration Length	2 m
Frequency	2856 MHz
Aperture radius (a)	~15 mm
Gradient	10 MV/m

Normal S band	
Acceleration Length	2 m
Frequency	2856 MHz
Aperture radius (a)	~10 mm
Gradient	20 MV/m

Final results

Performances of 100 random machines after orbit steering

Error type	Value
Offsets	100um/urad
Rotation	100urad

Electron source: 6.5 nC RF Gun

e-
$\mathrm{E} = 4.39$ GeV;
$\frac{\delta \mathrm{E}}{\mathrm{E}} \sim \mathbf{0.5\%}$;
$\mathbf{Q > 5.3\ nC}$;
$\sigma_z \sim 1$mm (0.9mm better);
$\varepsilon_{x,y} = 2$nm~10nm (5nm better);
$\sigma_x = 0.5$mm~1mm (can choose **1mm**);
$\sigma_y = 0.5$mm~1mm (can choose **1mm**);
$\sigma_{xp} \sim 10$ urad;
$\sigma_{yp} \sim 10$ urad

Electron source: 10 nC thermionic Gun

e-
$\mathrm{E} = 4.36$ GeV;
$\frac{\delta \mathrm{E}}{\mathrm{E}} \sim \mathbf{0.69\%}$;
$\mathbf{Q > 5.5\ nC}$;
$\sigma_z \sim 1$mm (0.8mm better);
$\varepsilon_{x,y} = 10$nm~50nm (25nm better);
$\sigma_x = 0.5$mm~1.5mm (can choose **1mm**);
$\sigma_y = 0.5$mm~1.5mm (can choose **1mm**);
$\sigma_{xp} \sim 20$ urad;
$\sigma_{yp} \sim 20$ urad

Before e+ target

After e+ target

e+
$\mathrm{E} = 214.7$ MeV; $\delta\mathrm{E}/\mathrm{E} = 3.75\%$; $\mathbf{Q = 12nC}$;
$\sigma_z = 1.878$ mm ; $\sigma_x = 4.49$ mm; $\sigma_y = 4.47$ mm
$\varepsilon_{x,y} = 13.9$ um, $\varepsilon_{Nx,y} = 5.87$ mm

Before damping ring (DR)

e+ positron yield: 2.2
$\mathrm{E} = 1.573$ GeV; $\delta\mathrm{E}/\mathrm{E} = 1\%$; $\mathrm{Q} = 12$nC;
$\sigma_z = 2.26$ mm;
$\varepsilon_{x,y} = 2.325\ \mu m$ $\varepsilon_{Nx,y} = 7$ mm (6 mm theory)

DR acceptance: $\varepsilon_{x,y} = 22.4\ \mu m$ $\delta\mathrm{E}/\mathrm{E} = 7.8\%$
$\varepsilon_z = 14.7\ mm$

The final **e+ yield** is about **7.8×10^{10}**$/6.25\times 10^{10}$ =**1.2**