Beam optics design for **PRAE** linac beamlines and **FCC-ee** injector linac

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Outline

- **PRAE** beam optics design

1. Radiobiology beamline
2. ProRad beamline

- **FCC-ee** injector linac

1. Bypass for e-/e+
2. Positron linac

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PRAE beam optics design

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- The PRAE project - The Platform for Research and Applications with Electrons, at LAL, in Orsay, Université Paris-Sud

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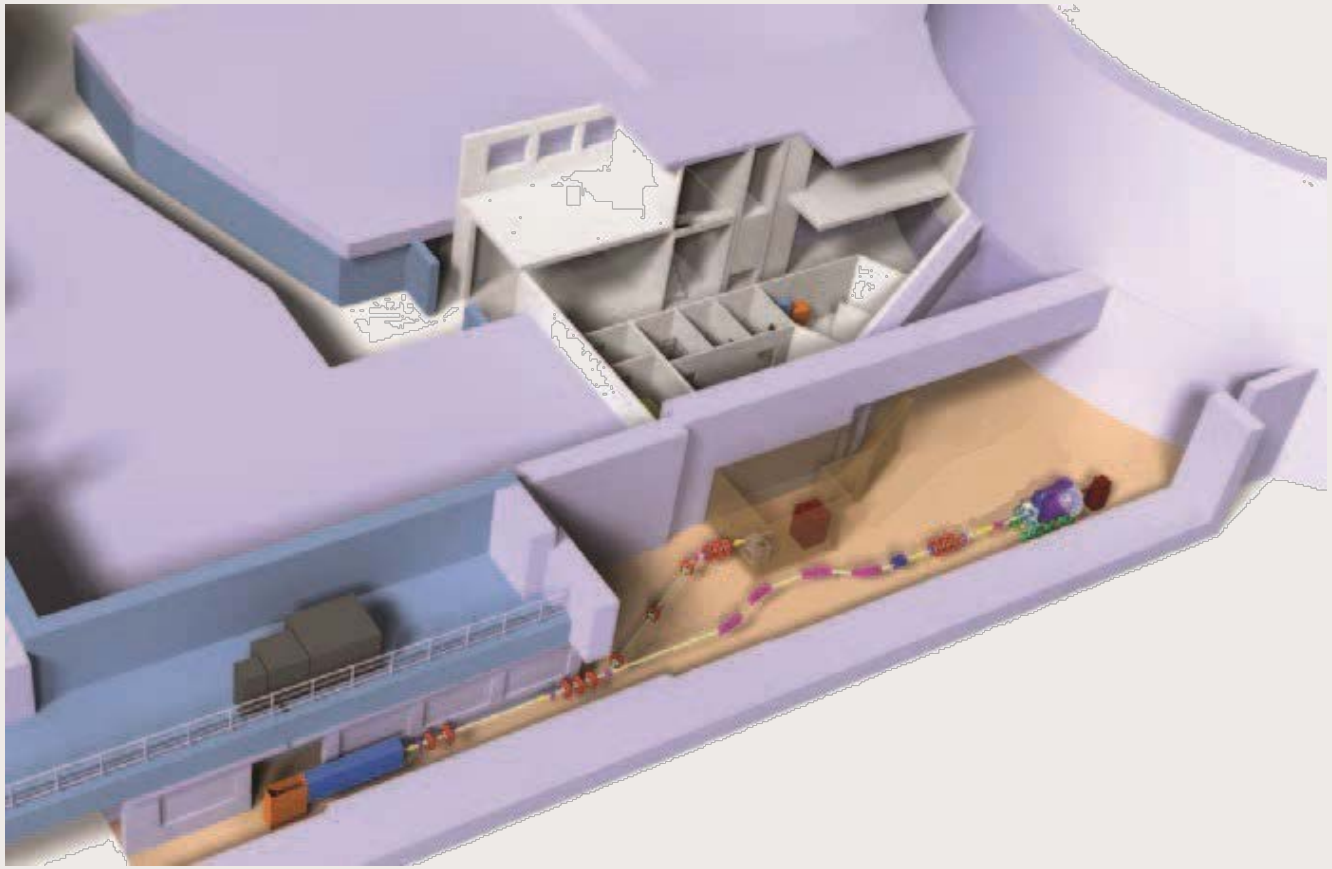

PRAE beam optics design

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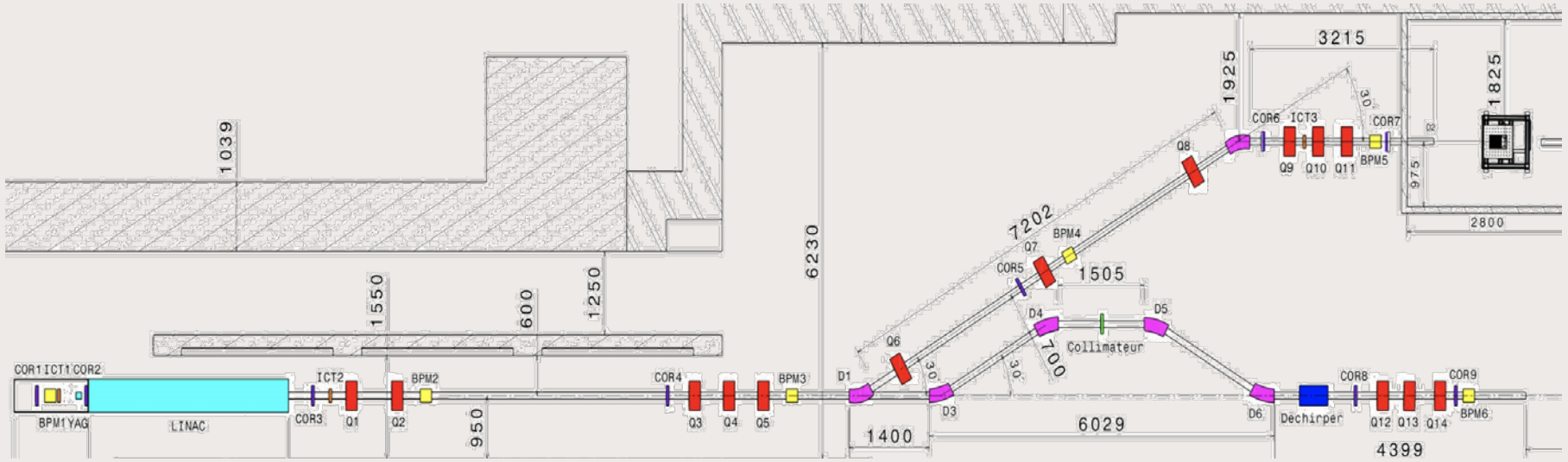
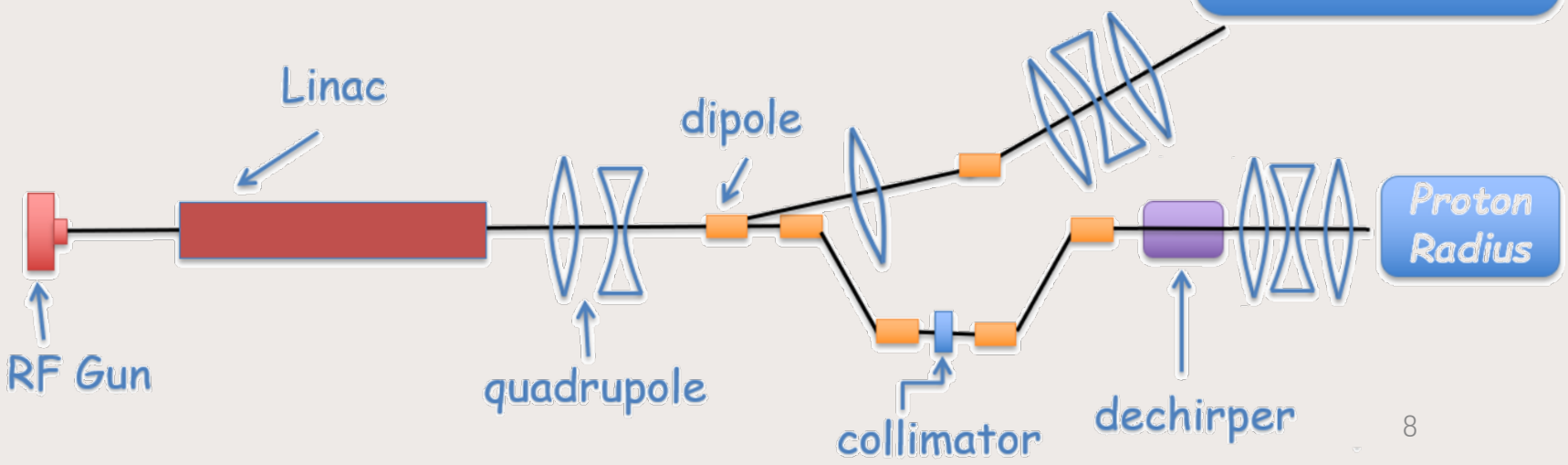
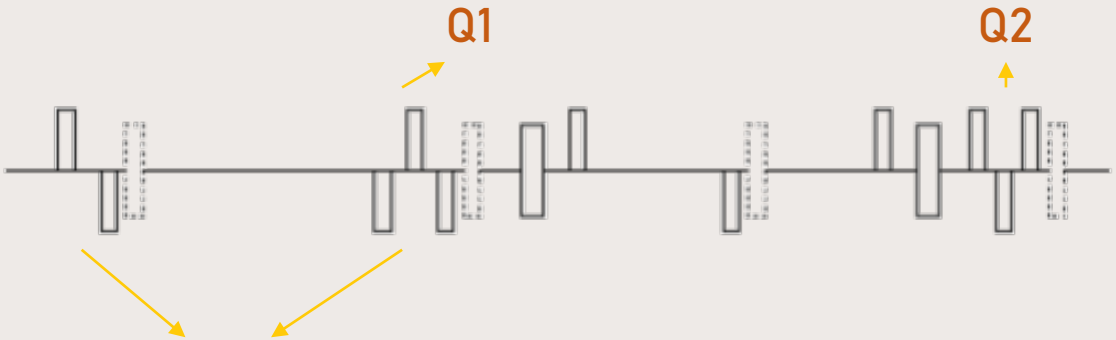
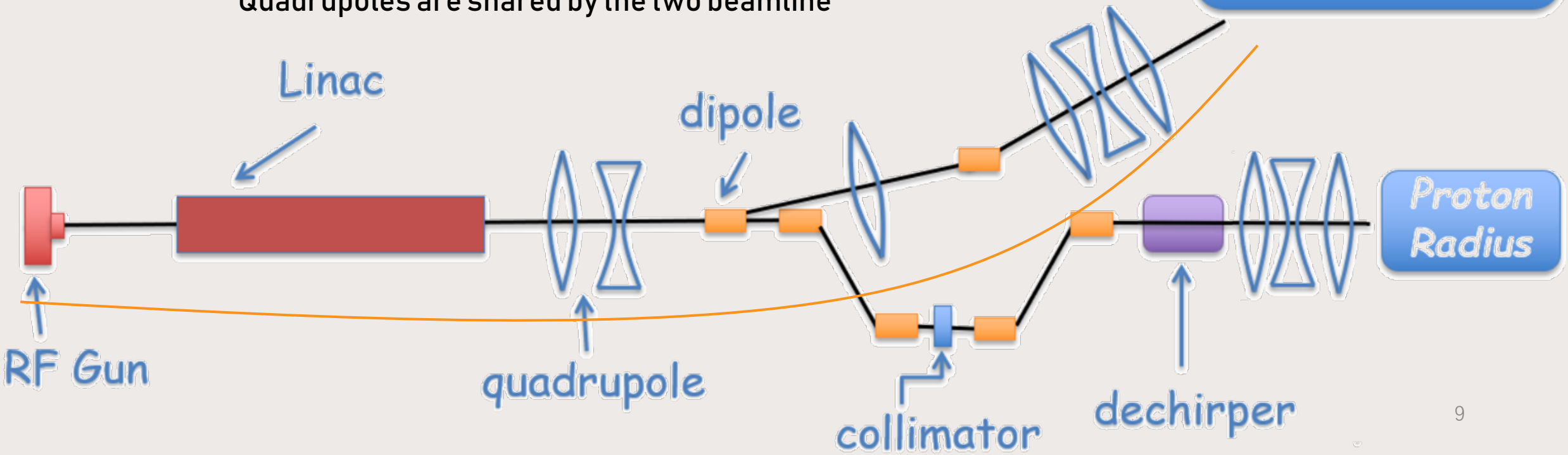




1. Radiobiology beamline



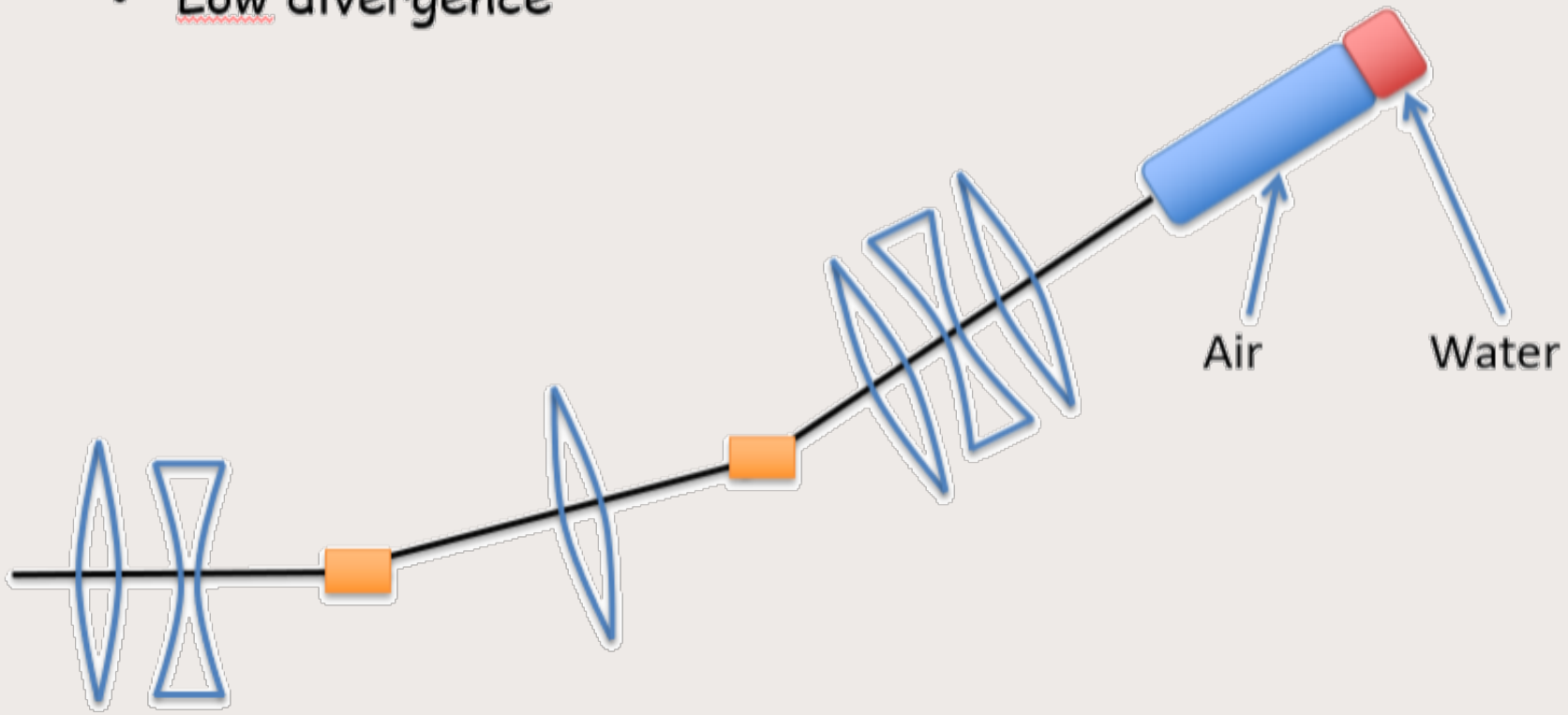
Quadrupoles are shared by the two beamline



1. Radiobiology beamline

Two scenarios:

- Mini Beam
  - $\sigma_{x,y}$ = 400 – 700 μm after 10 cm air + 3 cm water
  - Low divergence
- FLASH beam
  - $\sigma_{x,y}$ = 10 mm × 10 mm , Δt = 100 ms
  - $\sigma_{x,y}$ = 26 mm × 18 mm , Δt = 500 ms

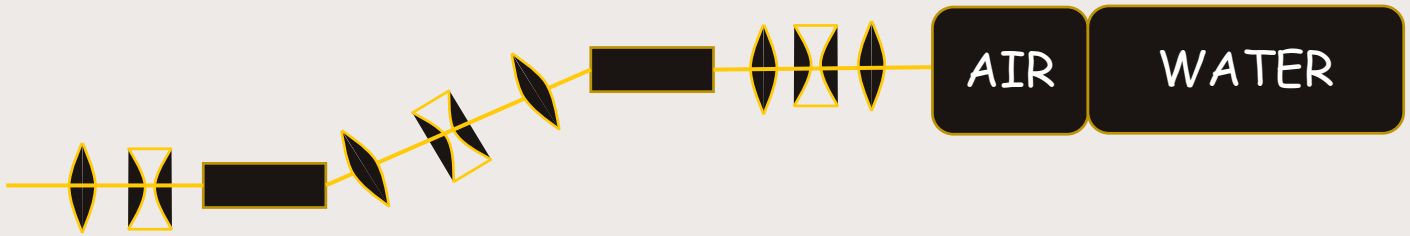


1. Radiobiology beamline

Simulation environment

- Beam Properties (70 MeV)
  - Charge: 1 nC/bunch
  - Transverse Size: ~ $200\ \mu m$
  - Bunch length: 2 ps
  - Normlized Emittance: < 10 mm.mrad (For mini beam)
  - Energy spread: ~ 0.3%
  - Repetion rate: 50 Hz

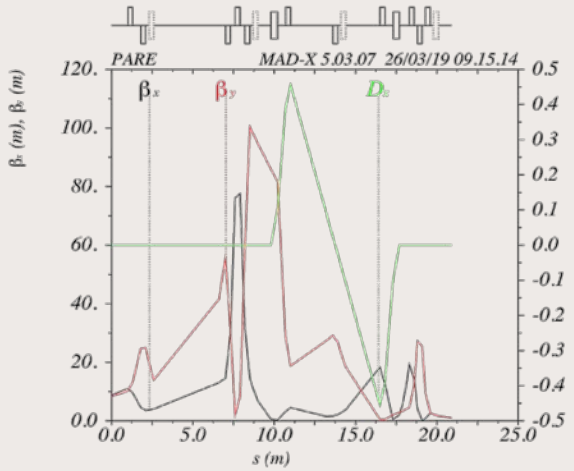
- Beam line tracking: placet
- Beam irradiation: Geant4 (Penelope Physics)
  - Mini Beam – 10 cm air + 30 cm water
  - FLASH Beam – 100 cm air + 30 cm water

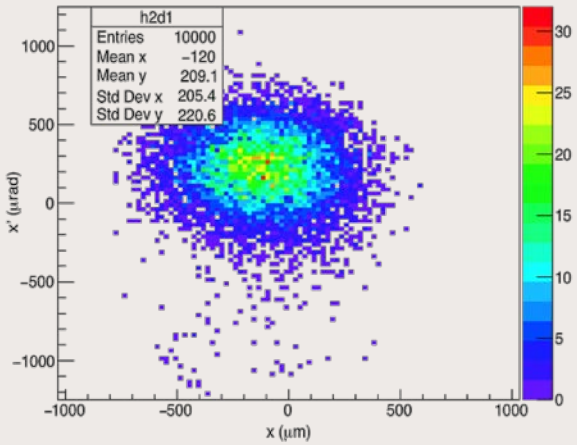


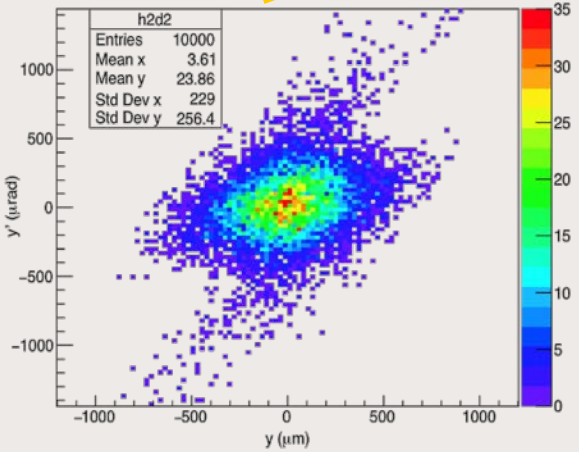
MINI beam – 70 MeV

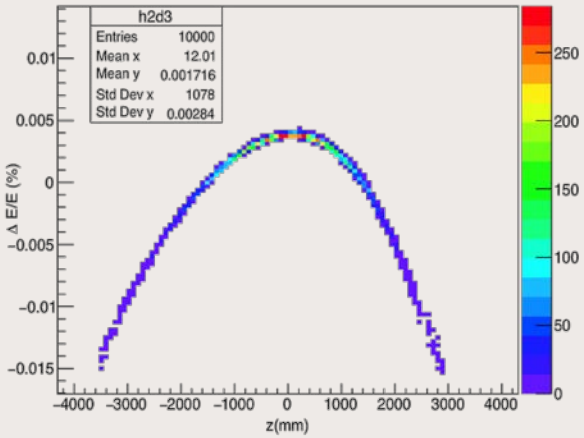
- $\sigma_x = 207\ \mu m, \sigma_y = 240\ \mu m$ $(5.31mm \cdot mrad)$

At the end of vaccum

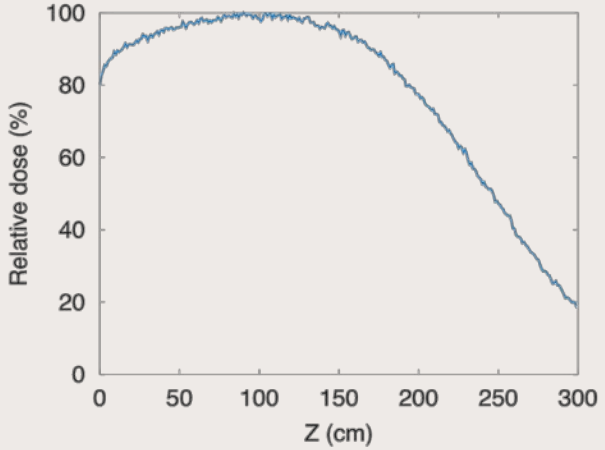




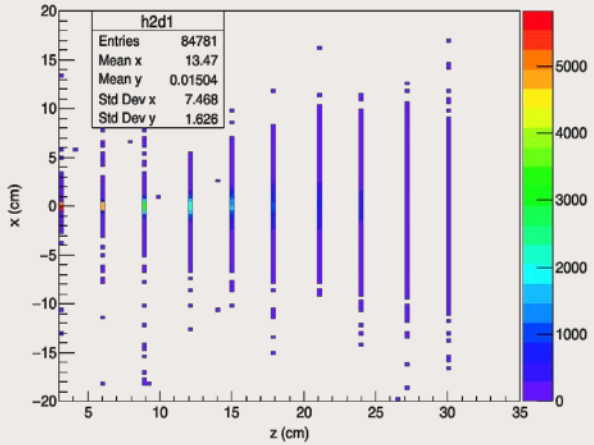




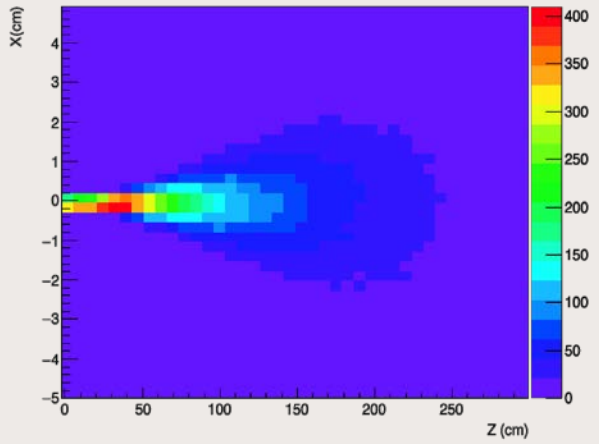
Relative Dose



Beam size along Z



Deposited Eenergy in x-z plan



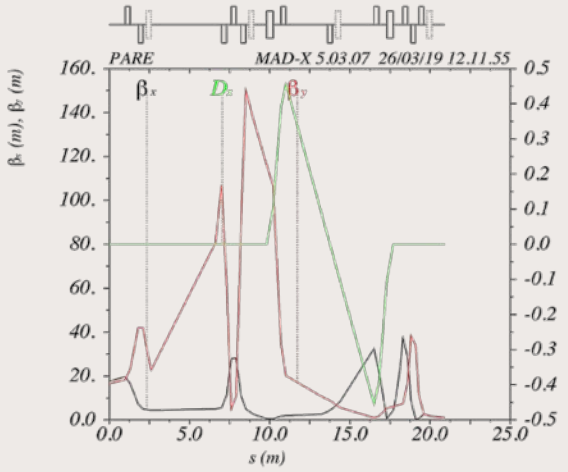
In the Water

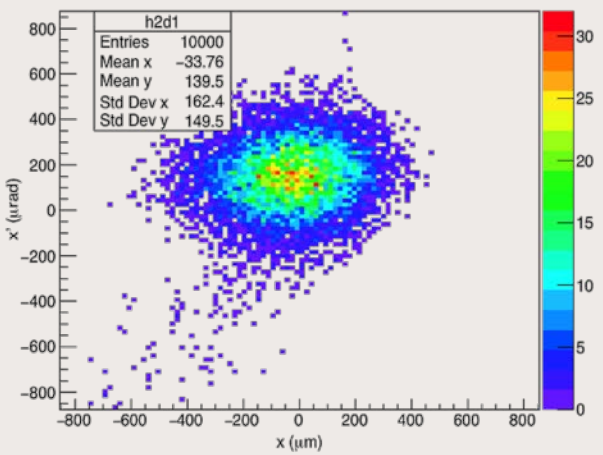
	Air	Water
σ_x(mm)	0.25	35.9
σ_y(mm)	0.29	36.6

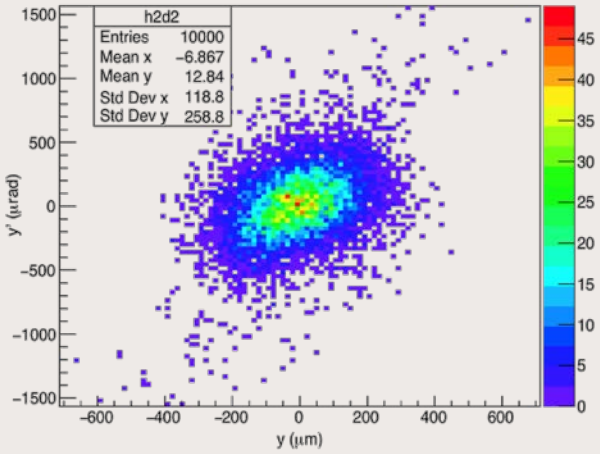
MINI beam – 140 MeV

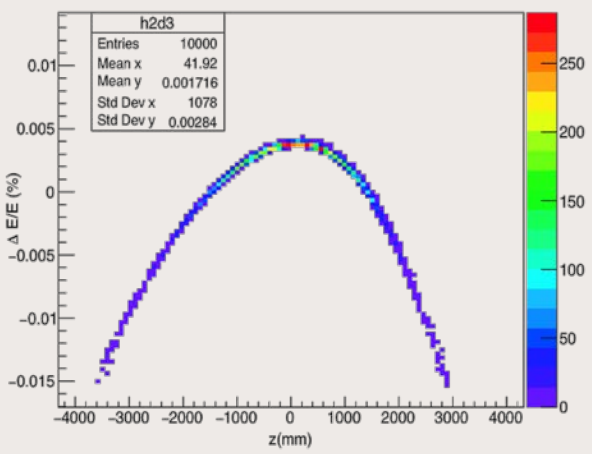
- $\sigma_x = 170\ \mu m, \sigma_y = 142\ \mu m$

At the end of vaccum

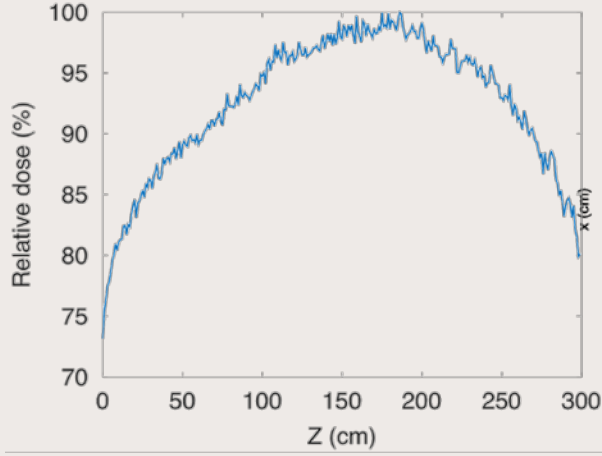




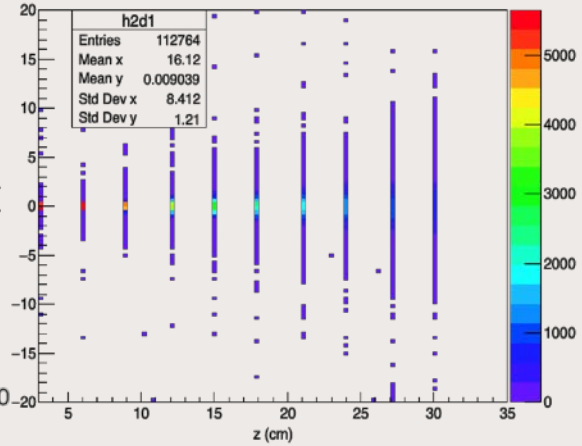




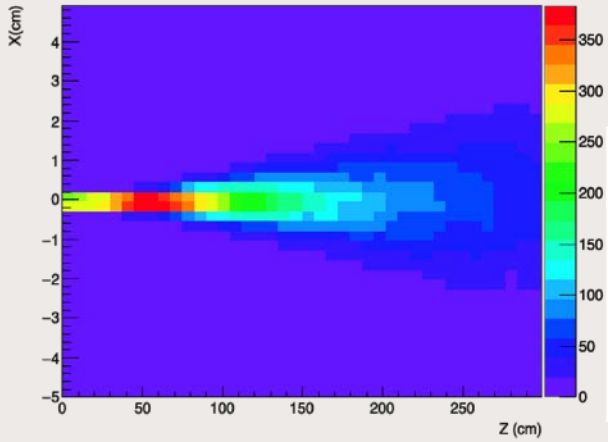
Relative Dose



Beam size along Z



Deposited Eenergy in x-z plan



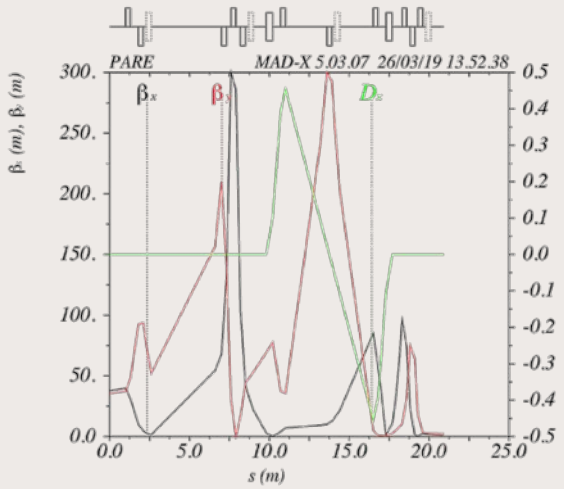
In the Water

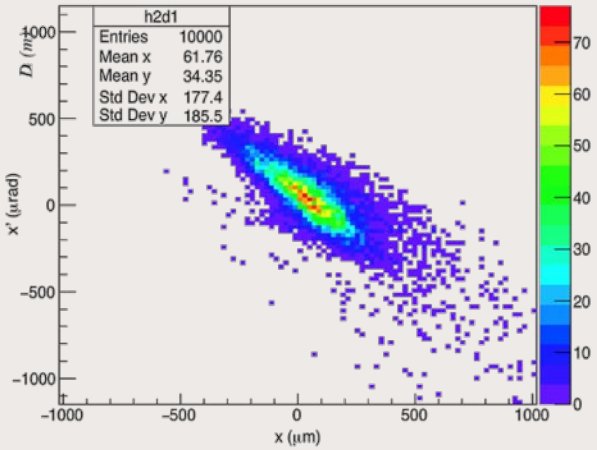
	Air	Water
σ_x(mm)	0.18	20.8
σ_y(mm)	0.15	21.2

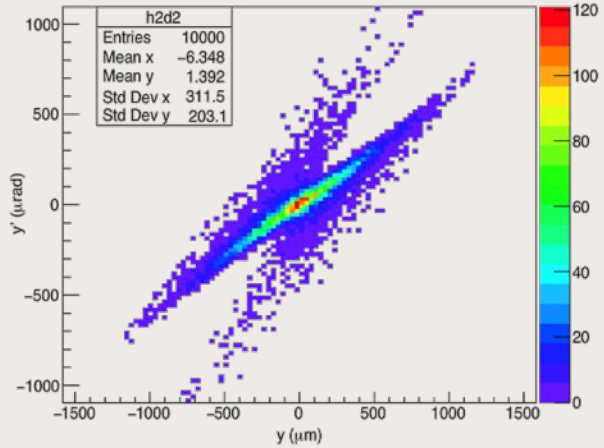
MINI beam – 300 MeV

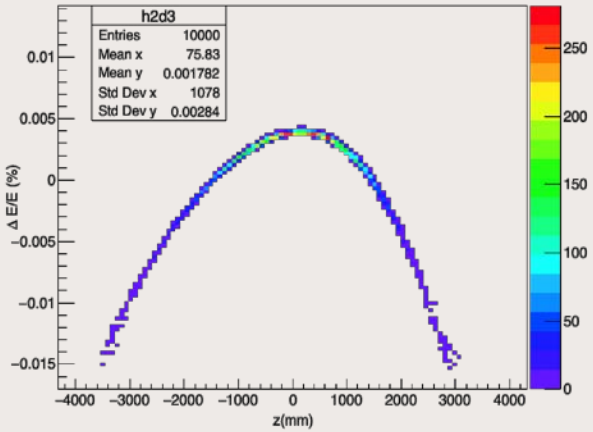
- $\sigma_x = 321\ \mu m, \sigma_y = 314\ \mu m$

At the end of vaccum

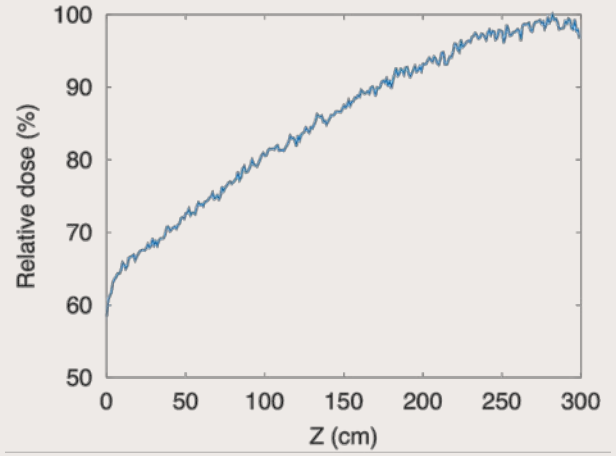




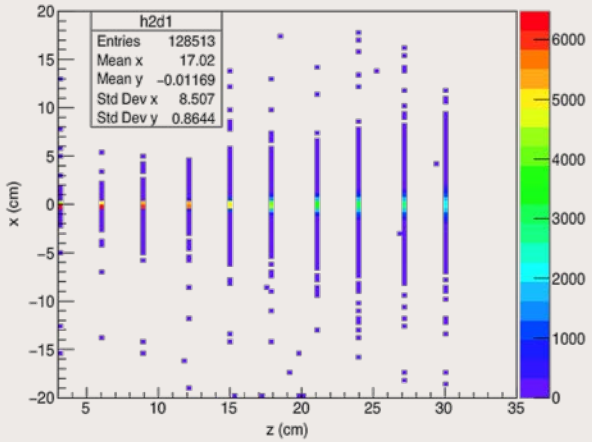




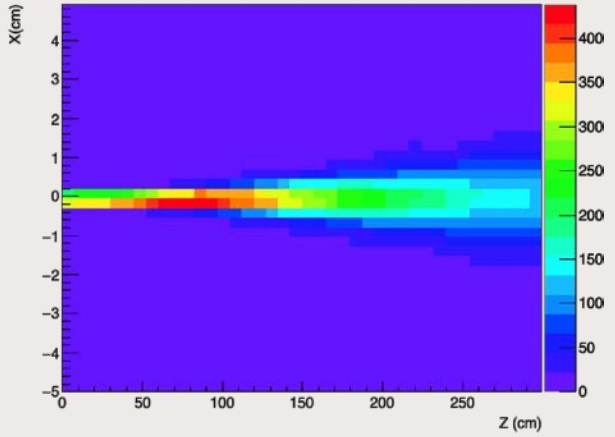
Relative Dose



Beam size along Z



Deposited Eenergy in x-z plan



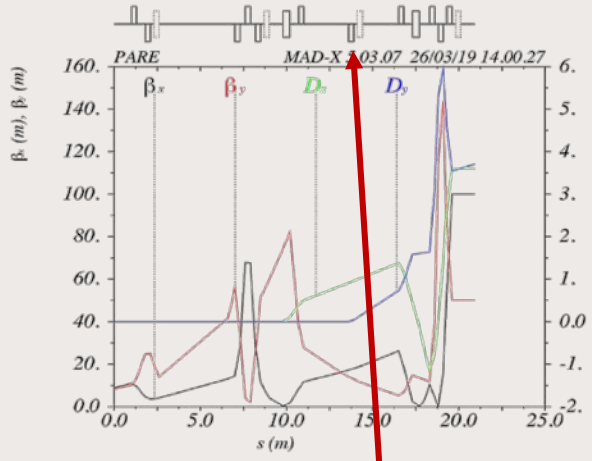
In the Water

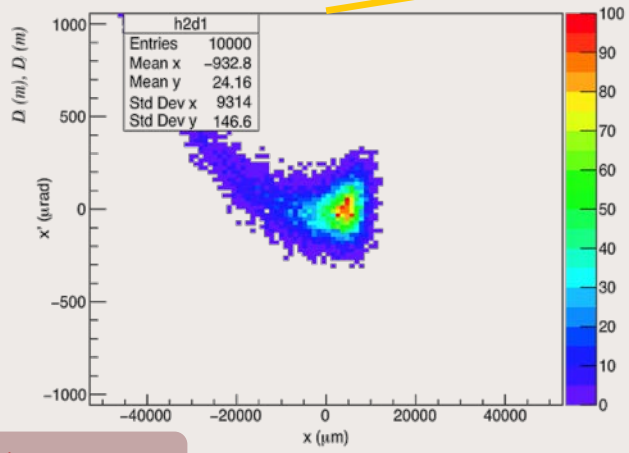
	Air	Water
σ_x(mm)	0.34	11.8
σ_y(mm)	0.33	11.7

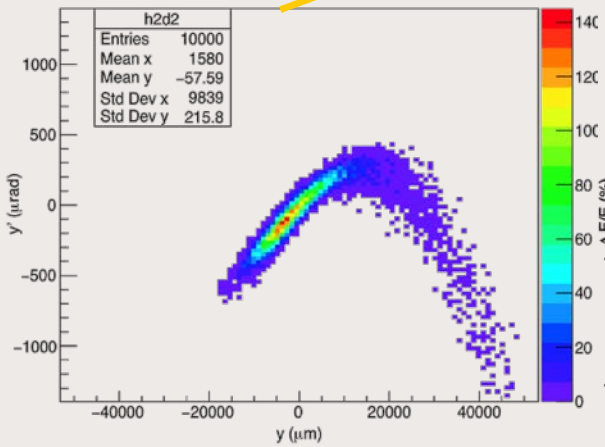
FLASH beam – 70 MeV

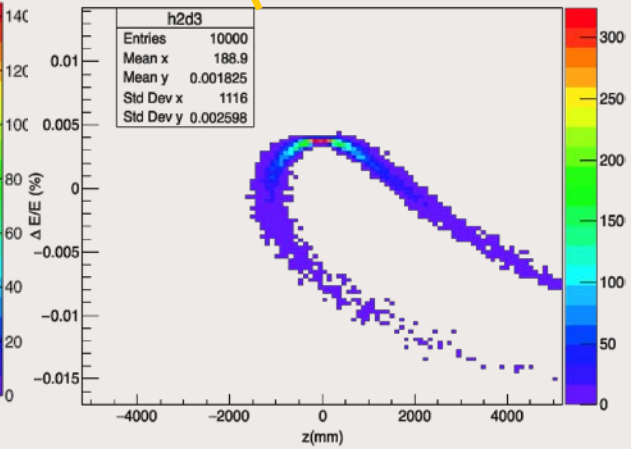
- $\sigma_x = 9.9\ mm, \sigma_y = 10.3\ mm$

At the end of vaccum



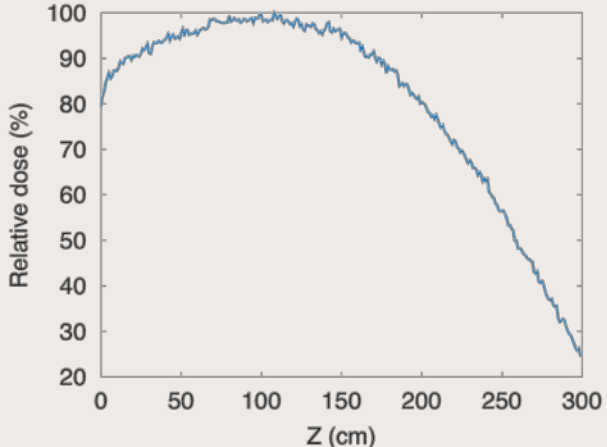




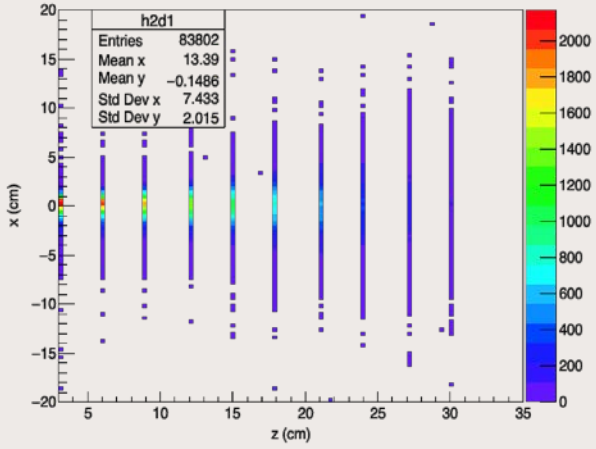


Skew Quad is used to introduce vertical dispersion

Relative Dose

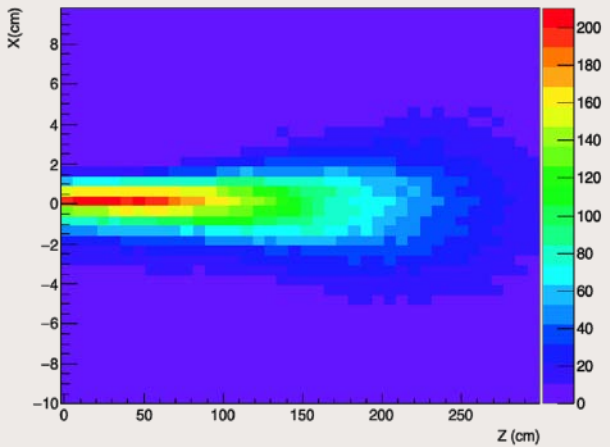


Beam size along Z



Deposited Eenergy in x-z plan

The air thick is 1 meter



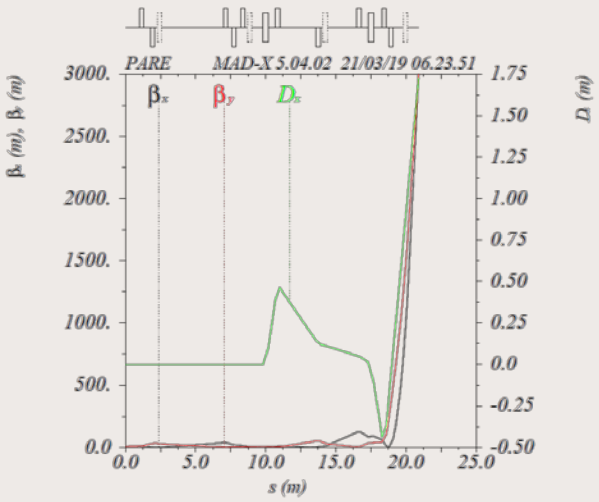
In the Water

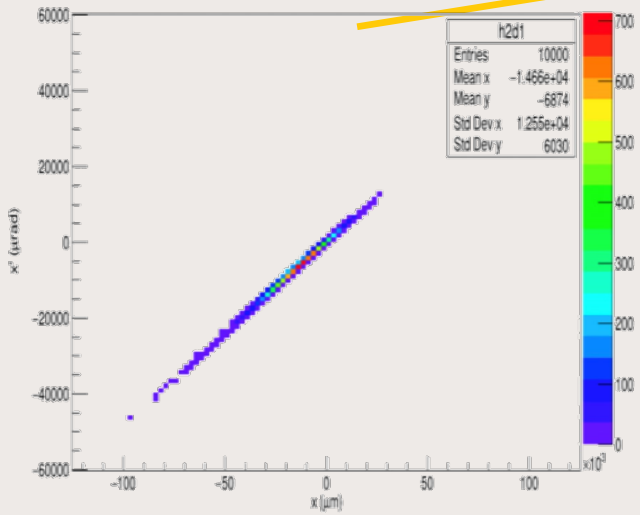
After	Air	Water
Left e^-	100%	20%
σ_x(mm)	11.4	37.3
σ_y(mm)	12.0	37.0

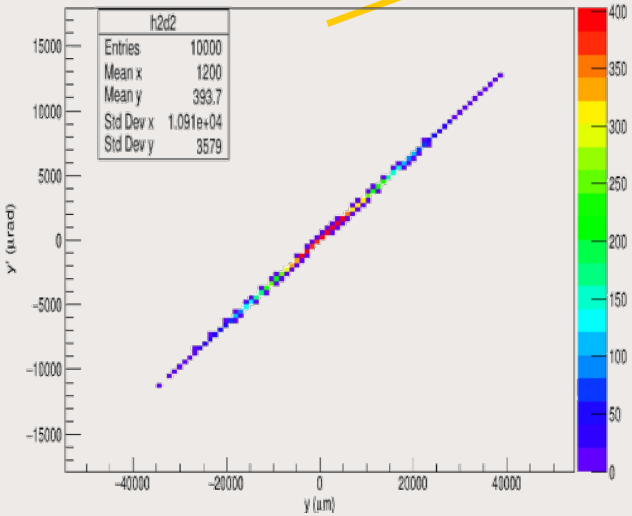
FLASH beam – 70 MeV

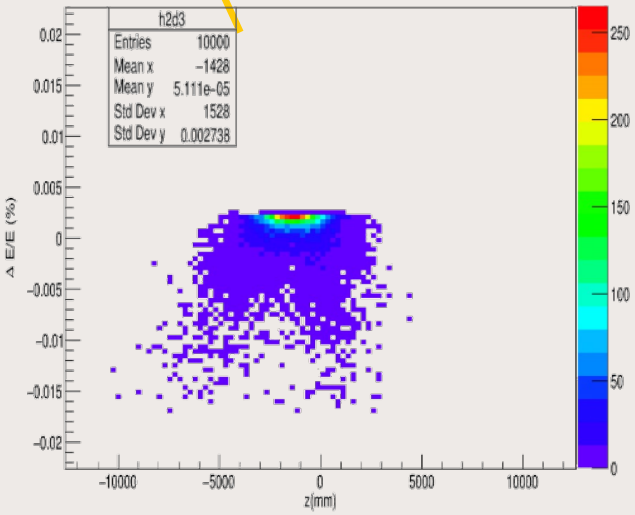
- $\sigma_x = 12.55mm, \sigma_y = 10.91mm$

At the end of vaccum

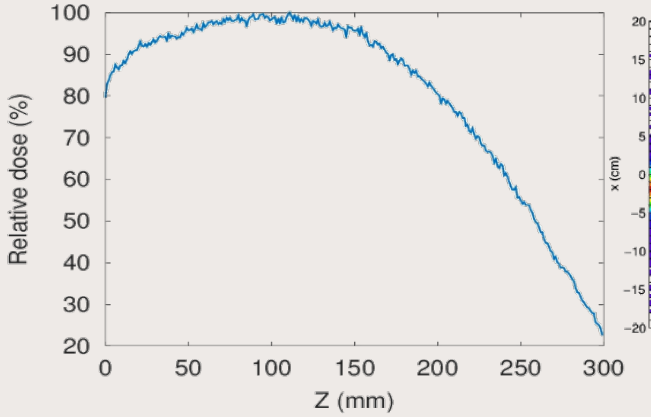




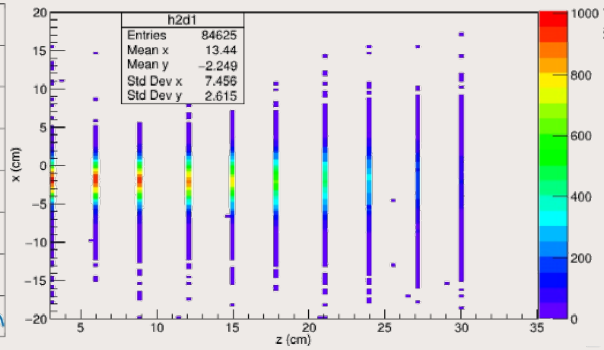




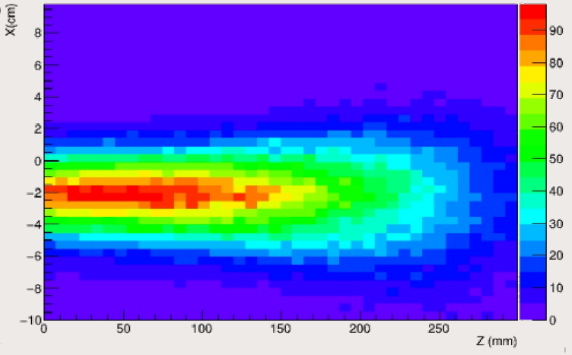
Relative Dose



Beam size along Z



Deposited Eenergy in x-z plan



The air thick is 1 meter

In the Water

after	exit	air	9cm water	15cm water	30cm water
σ_x (mm)	12.55	21.07	21.39	24.64	40.53
σ_y (mm)	10.91	17.32	17.63	21.56	38.66

Outline

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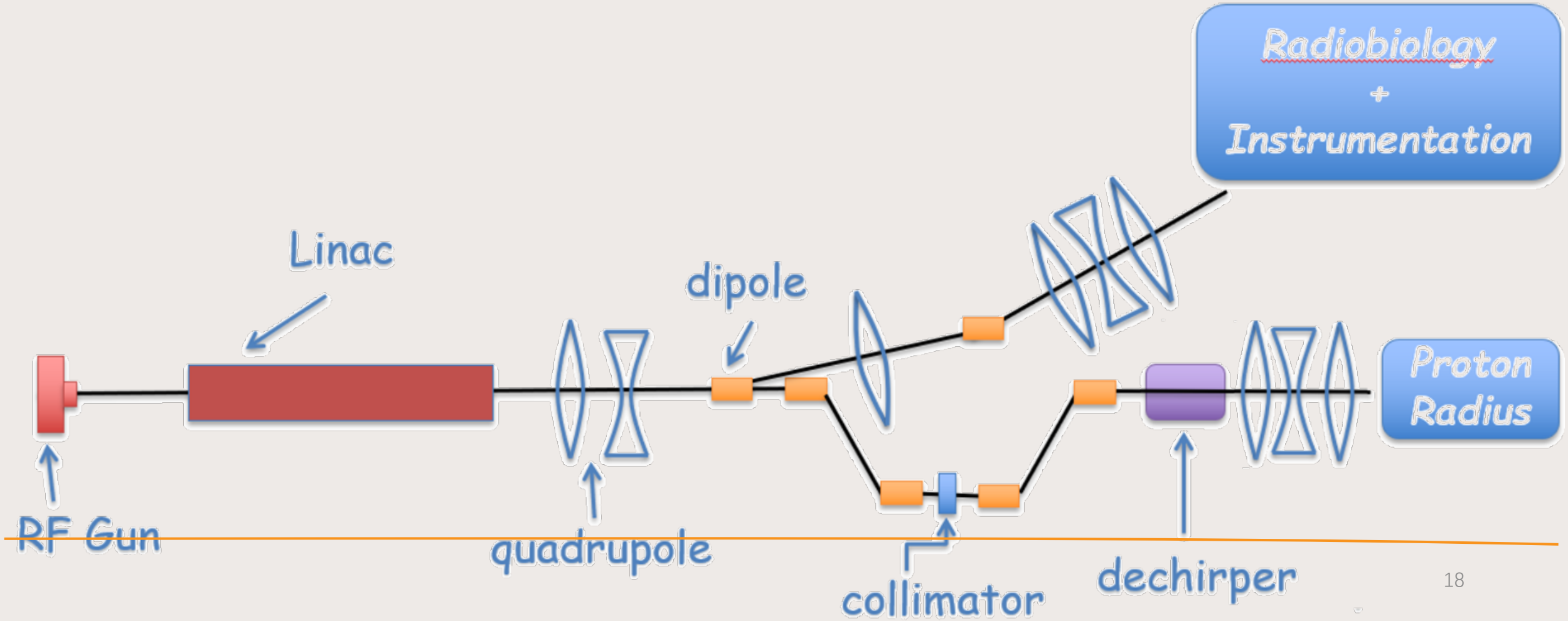
2. ProRad beamline

- FCC-ee injector linac

1. Bypass for e-/e+
2. Positron linac

2. ProRad beamline

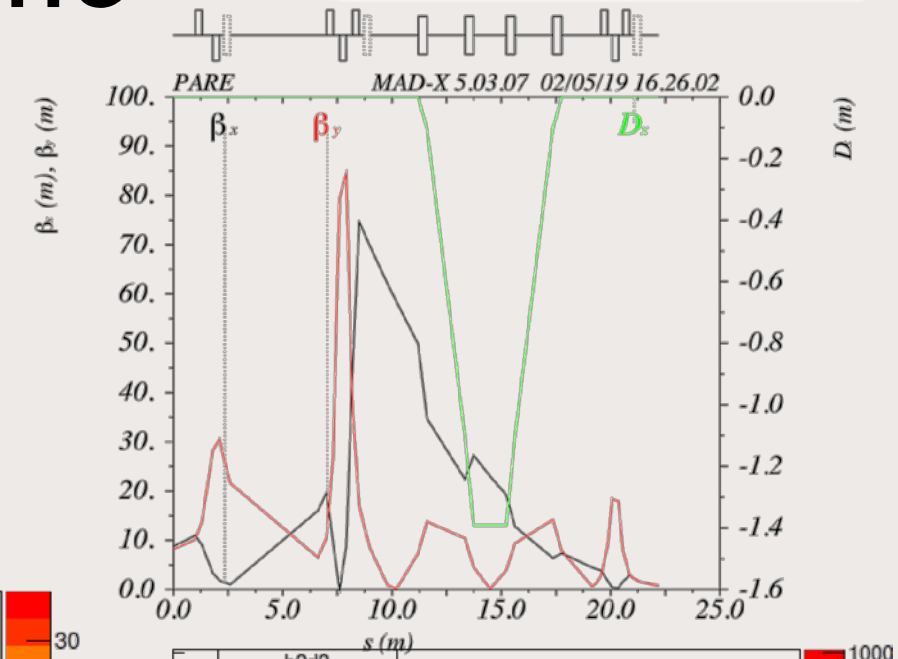


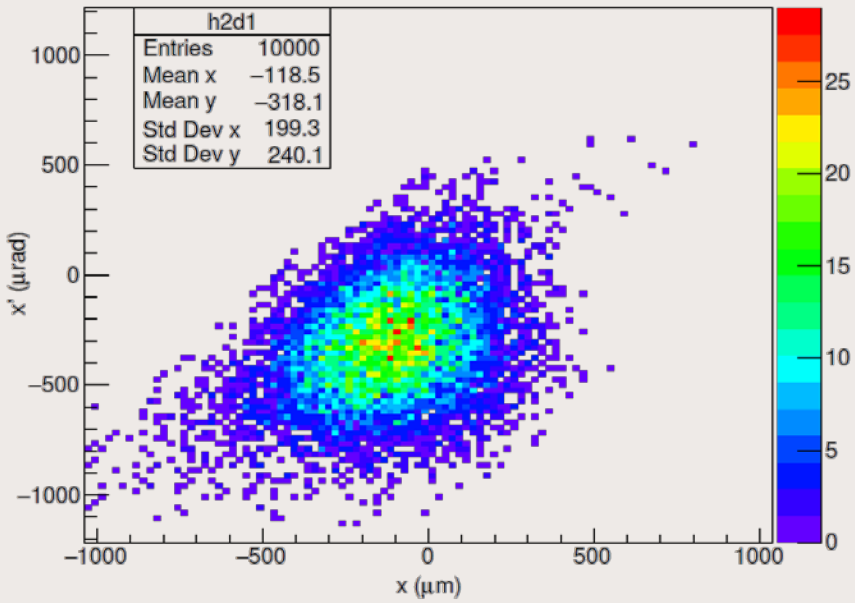
2. ProRad beamline

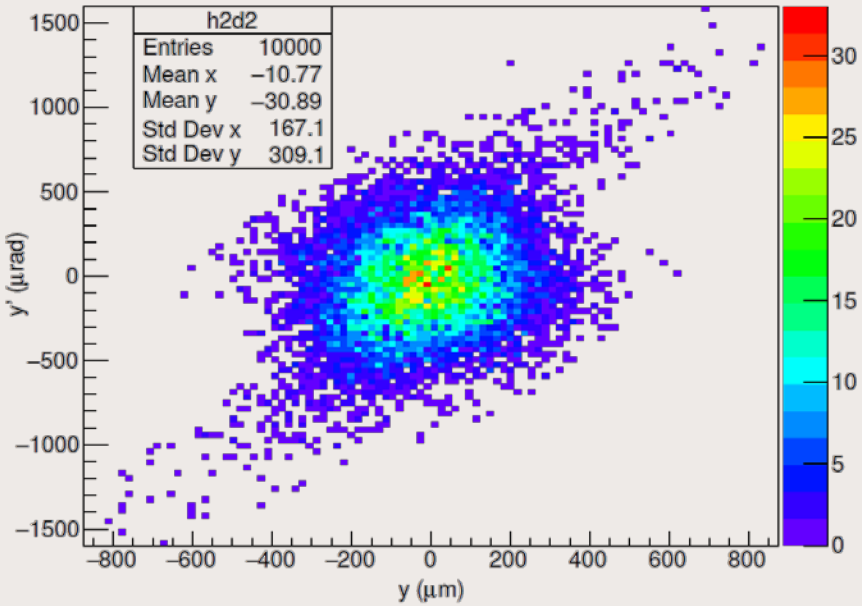
- σ_x = 20 – 30 μm
- σ_y = 100 – 200 μm
- $\sigma_E / E < 5 \times 10^{-4}$
- $\sigma_{x',y'}$ < 50 μrad
- Q = 10 – 100 pC

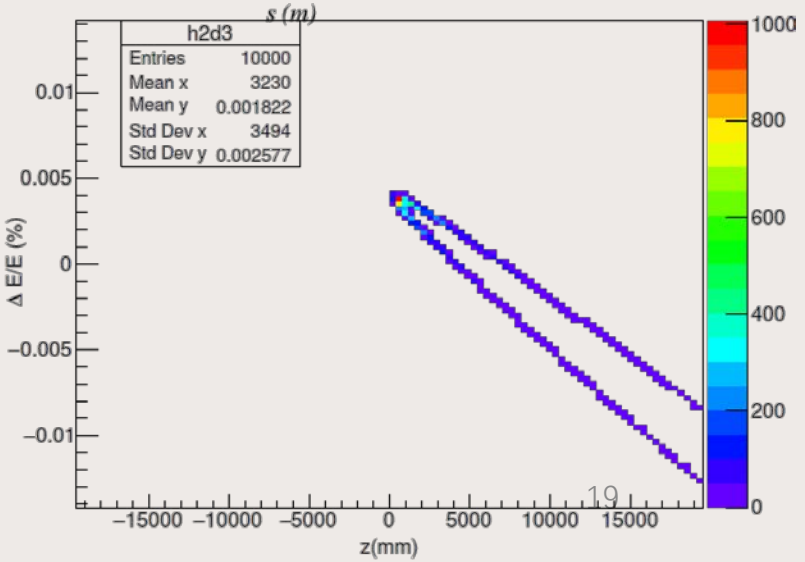
$$E_0 = 70.298 MeV$$

$$\beta_x = \beta_y = 0.8m$$
$$D_X = D_Y = 0$$



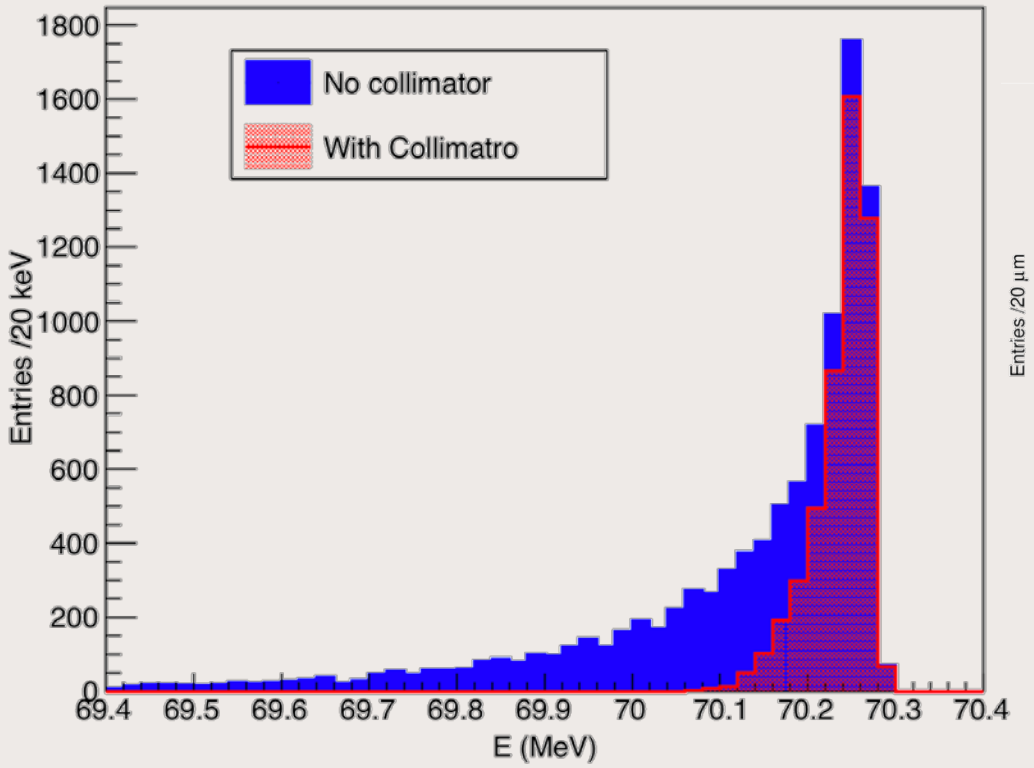


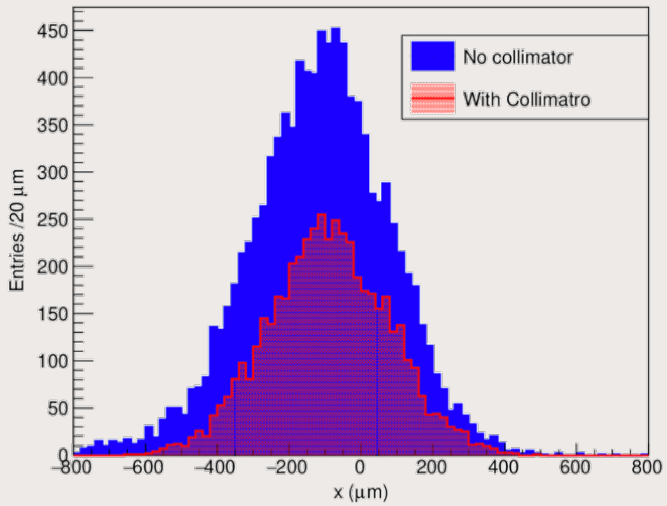


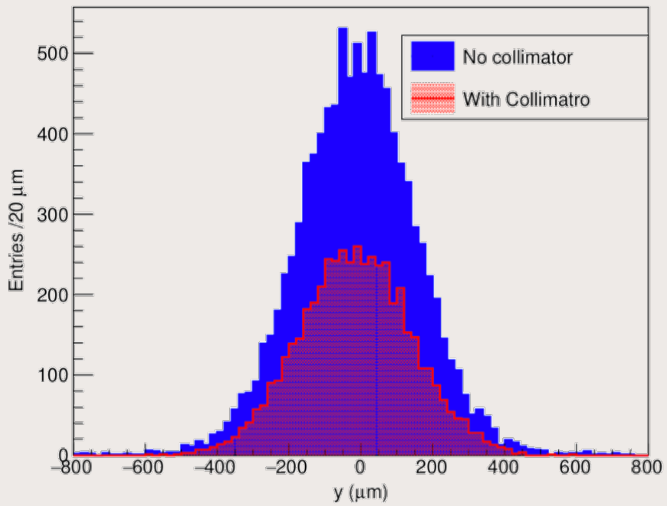


2. ProRad beamline

1. **The effect of collimator**
   - **1m long, 2mm aperture radius**
   - **48% survived particles**
   - **Energy spread: ~2e-3 -> 4.2e-4**



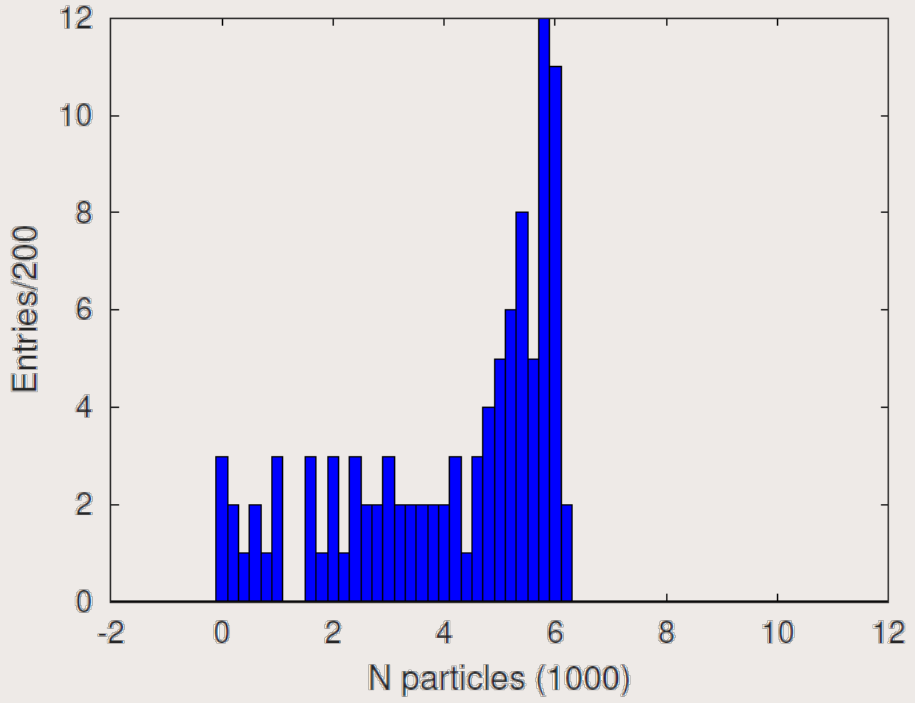


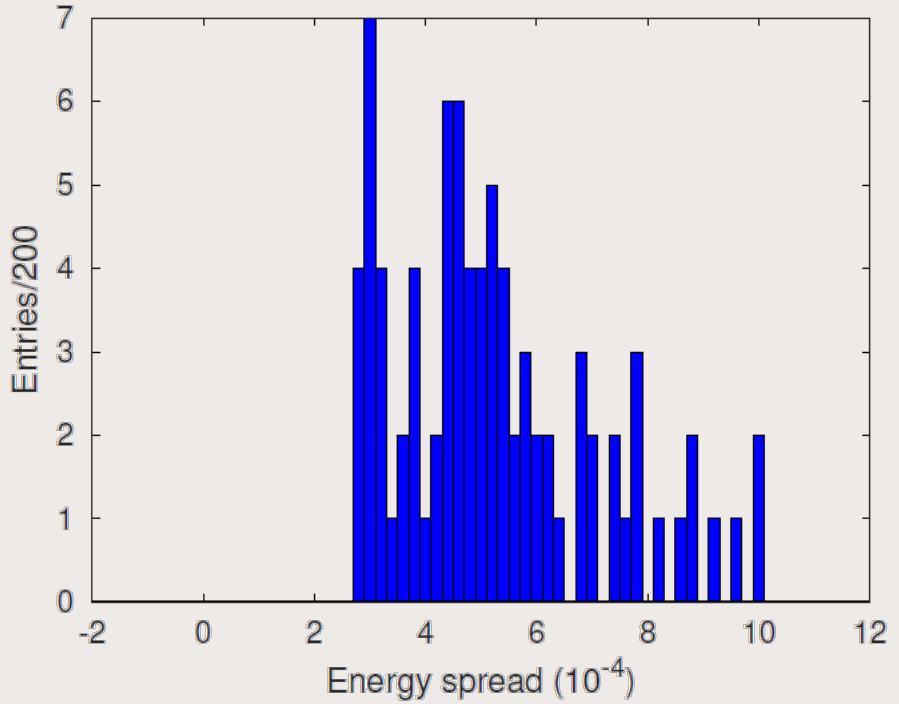


2. ProRad beamline

2. The misalignment tolerance study

- **100um, 100urad error for magnets and collimator, 200 times**
- **survived particle large than 20%, the possibility is 45%**
- **20um and 20urad provide 93% possibility**

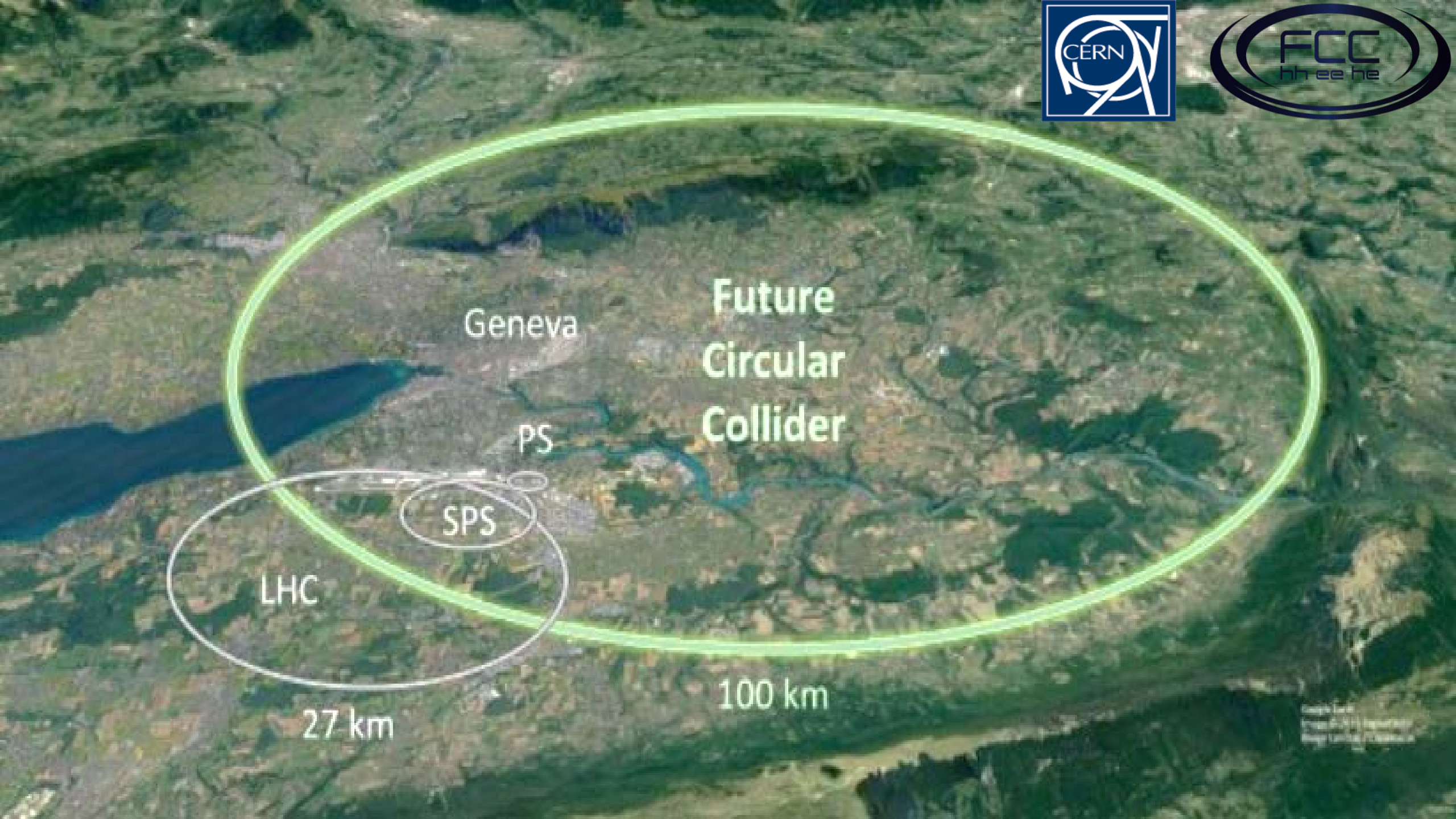




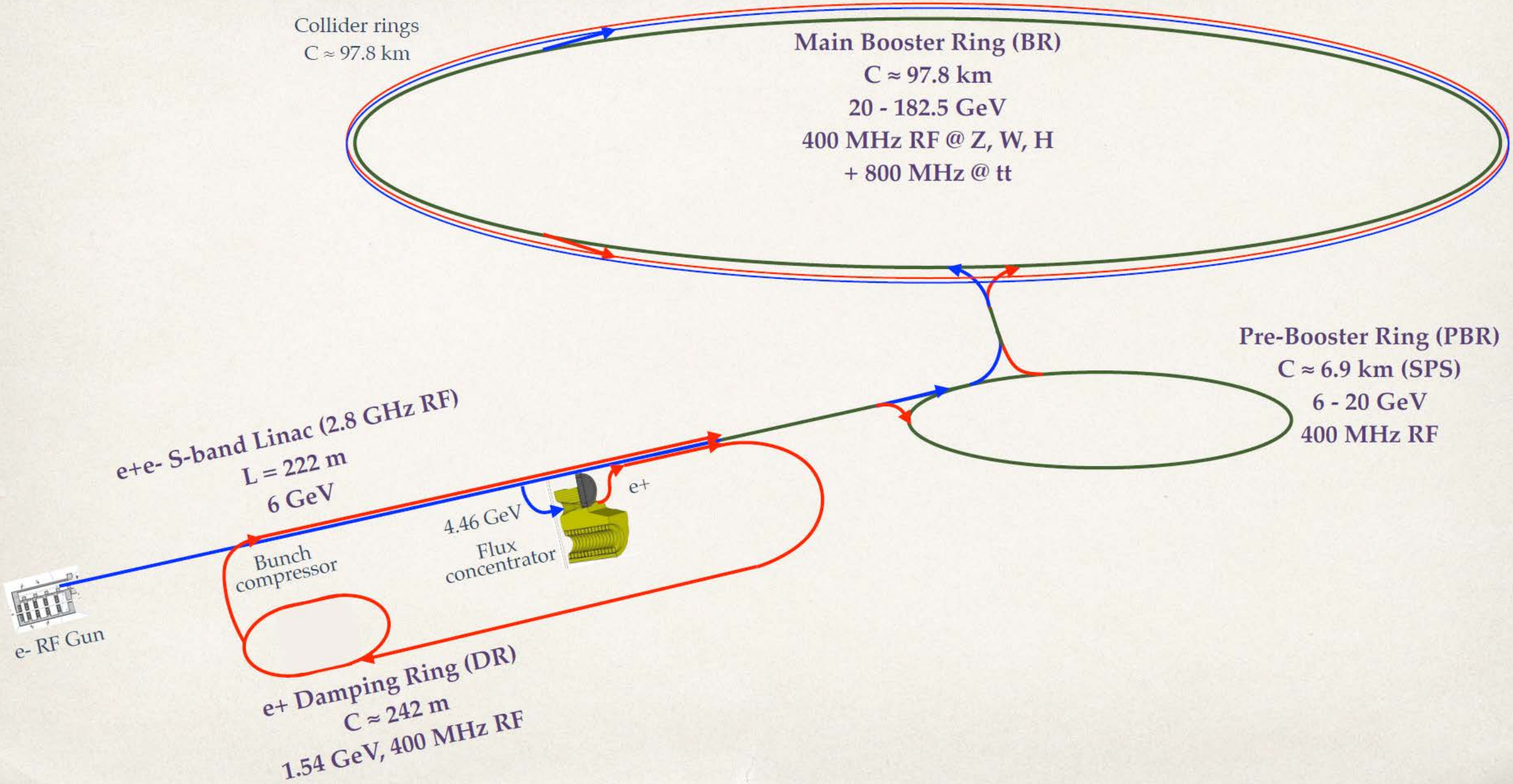
100um, 100urad

Outline

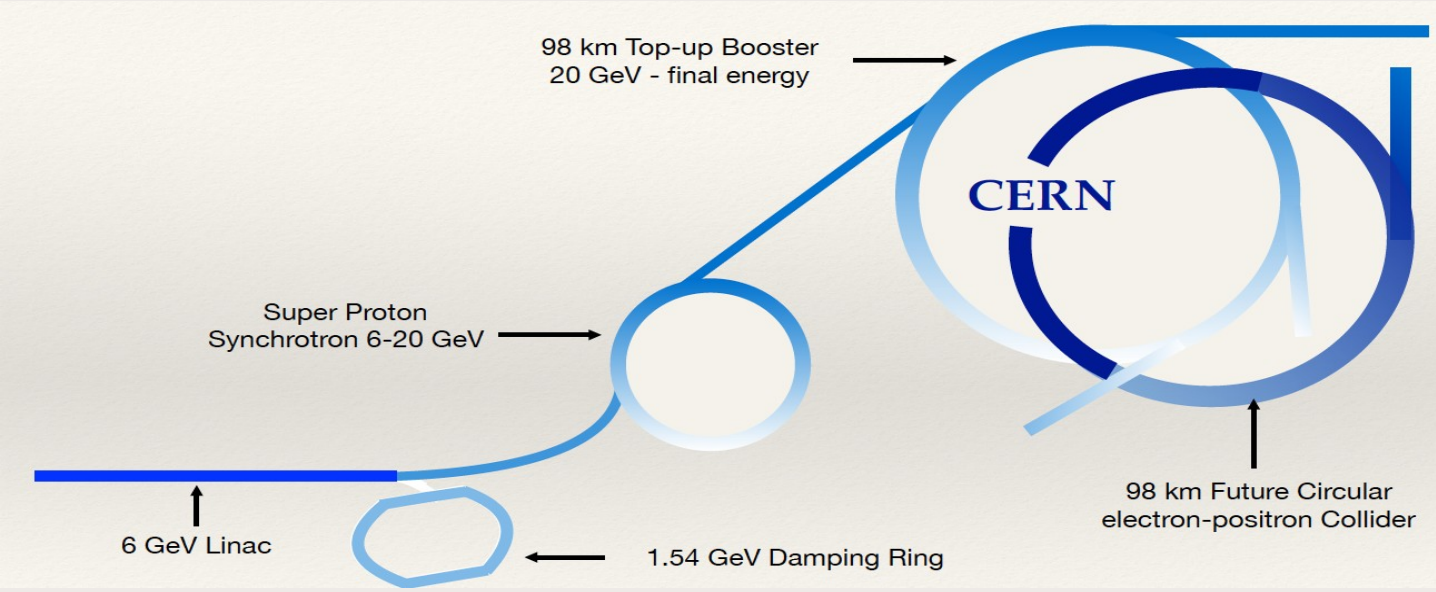
- PRAE beam optics design
1. Radiobiology beamline
2. ProRad beamline
- **FCC-ee** injector linac
1. Bypass for e-/e+
2. Positron linac

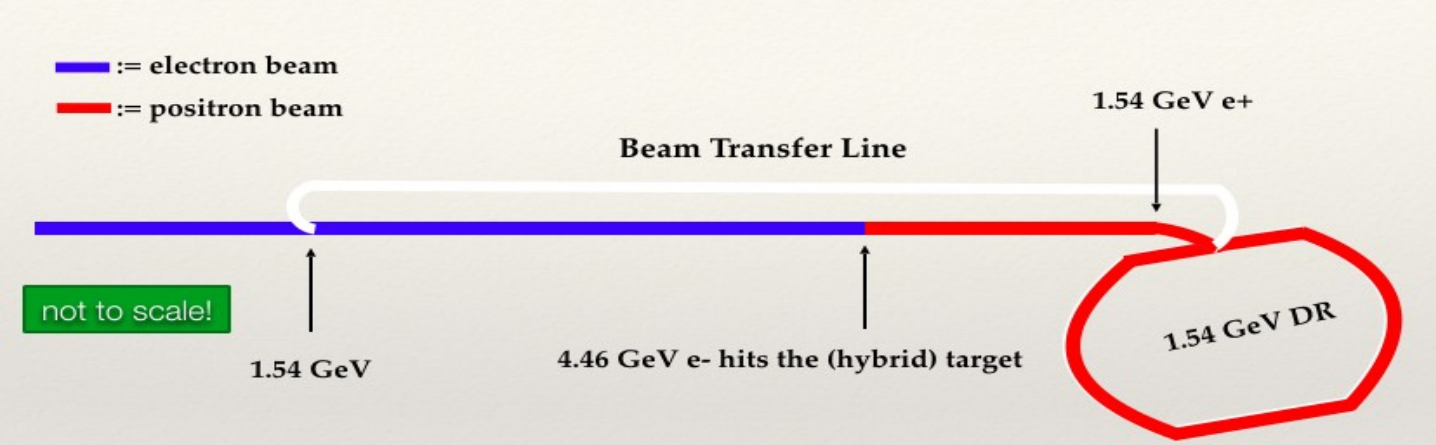

Future
Circular
Collider
Geneva
PS
SPS
LHC
27 km
100 km

The baseline layout in the CDR



FCC-ee injector complex





SLC/**SuperKEKB**-like 6 GeV S-band linac accelerating 1 or **2** bunches (2e10/bunch), with repetition rate **100-200 Hz**

Same linac used for e+ production

@ 4.46 GeV

e+ beam emittances reduced in DR

@ 1.54 GeV

Injection @ **6 GeV** into pre-booster Ring (SPS or new ring) & acceleration to 20 GeV or 20 GeV linac

Injection to main Booster **@ 20 GeV**

and interleaved filling of e+/e- (**<20 min for full filling**) and continuous top-up

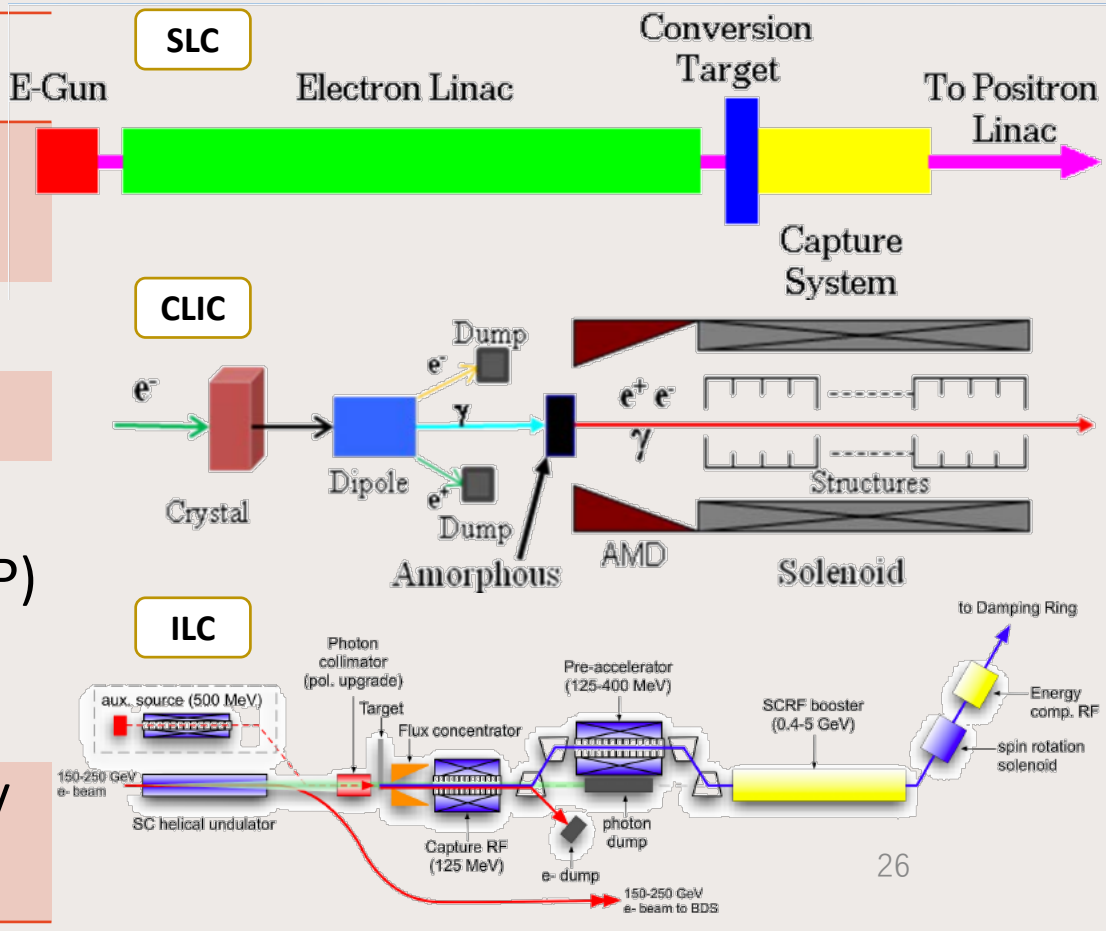
The main 6(20) GeV linac hosts the e+ source. The positrons are produced with 4.46(18.46) GeV e- beam

Brief introduction of positron production in e-/e+ colliders

- Linear collider: SLC, ILC, CLIC

SLC is the positron source model for existing and future colliders: DAFNE, KEKB, PEP-II, Beijing Tau-charm, superKEKB, FCC-ee, CLIC, ILC and LHeC

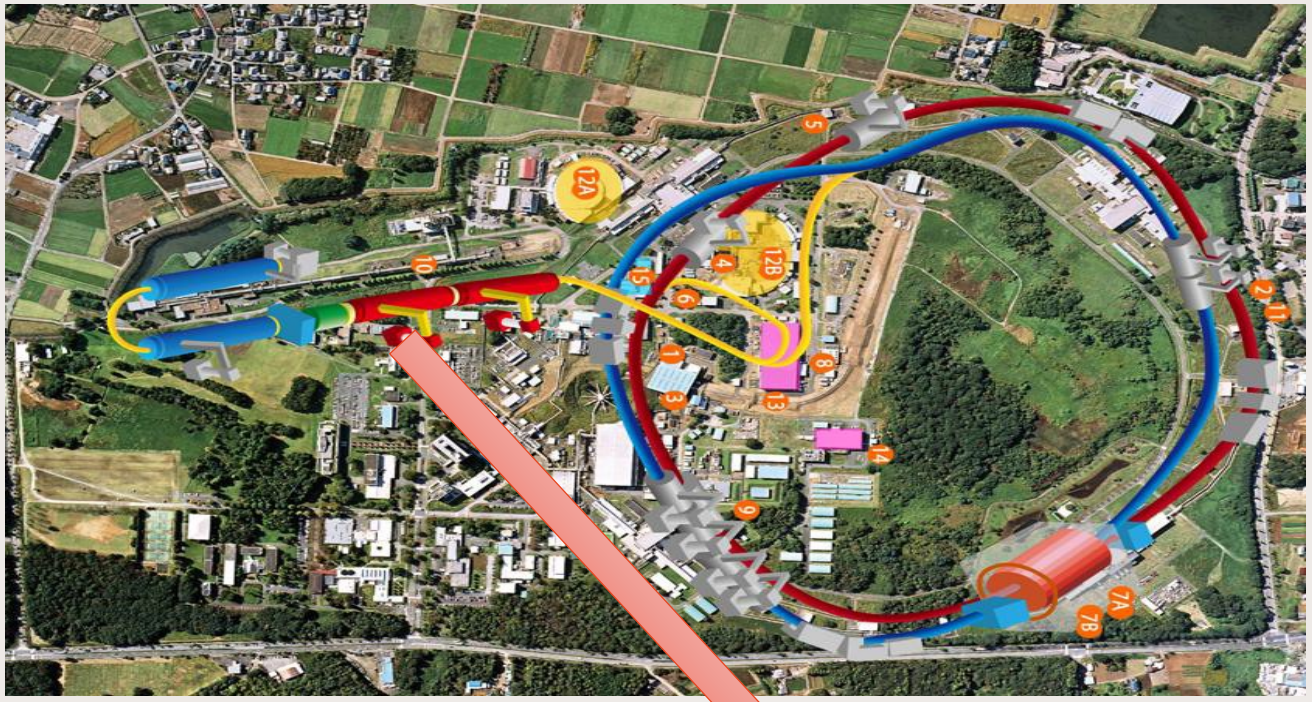
	SLC	CLIC	ILC
Primary e- energy	33 GeV	5 GeV	125 GeV
e- / bunch	4.8 – 8 nC	1.63 nC	3.2 nC
Rep. rate	120 Hz	50 Hz	5 Hz
e+ yield (e+/e-)	0.7 (final focus) 1.2 (after DR)	0.7(linac end) 2.1 (after AMD) 7.74(after W)	1.5 (goal after DP)
e+ generation	Conventional	Hybrid	Polarization / conventional

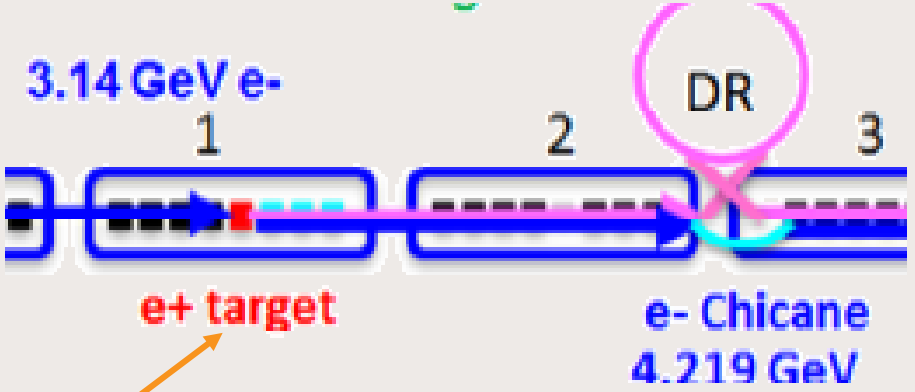


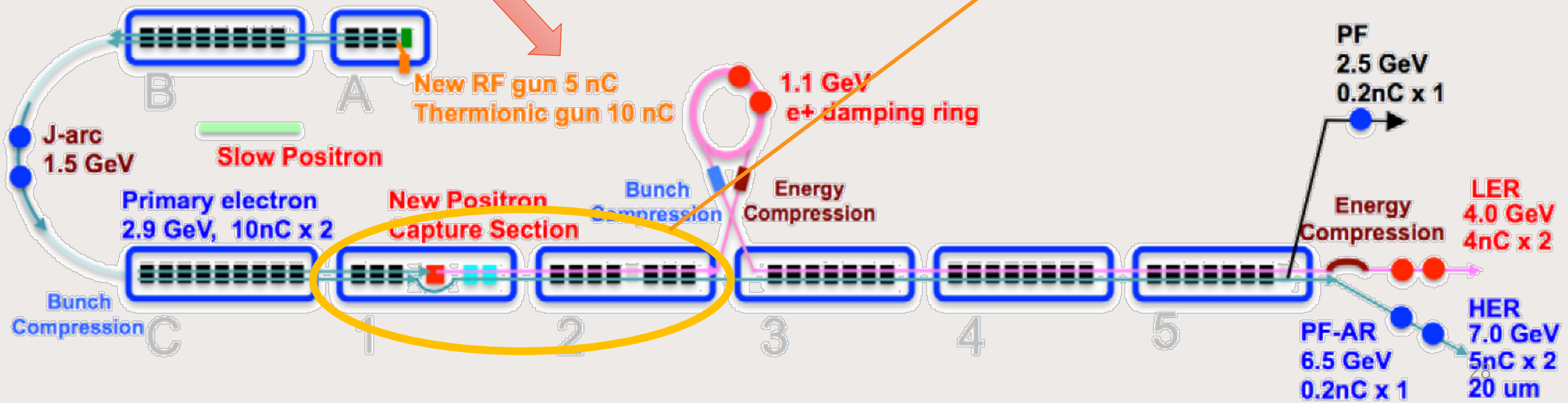
- Circular collider: LEP, BEPCII, SuperKEKB, CepC

	SLC	LEP	BEPCII	KEKB	SuperKEKB	CepC	FCC-ee
Primary e- energy	33 GeV	200 MeV	240 MeV	4 GeV	3.5 GeV	4 GeV	4.46 GeV
e- / bunch	4.8 – 8 nC	0.8 – 48 nC	10 nC	10 nC	10 nC	10 nC	8.8 nC
Rep. rate	120 Hz	100 Hz	50 Hz	50 Hz x2	50 Hz x2	100 Hz	200 Hz x2
Incident e- beam power	20 -30 kW	1kW (max)	< 500 W	4 kW	3.5 kW	4 kW(max)	15 kW
e+ yield (e+/e-)	0.7 (final focus) 1.2(after DR) 1.4 (before DR)	0.003 (linac end)	0.027(/GeV) (linac end) 0.043(/GeV) (solenoid end)	0.1 (design) (0.05 linac end)	0.4 (after DR, linac end) (0.2 achieved)	>0.3 (after capture section, FC)	0.7 (after CS)

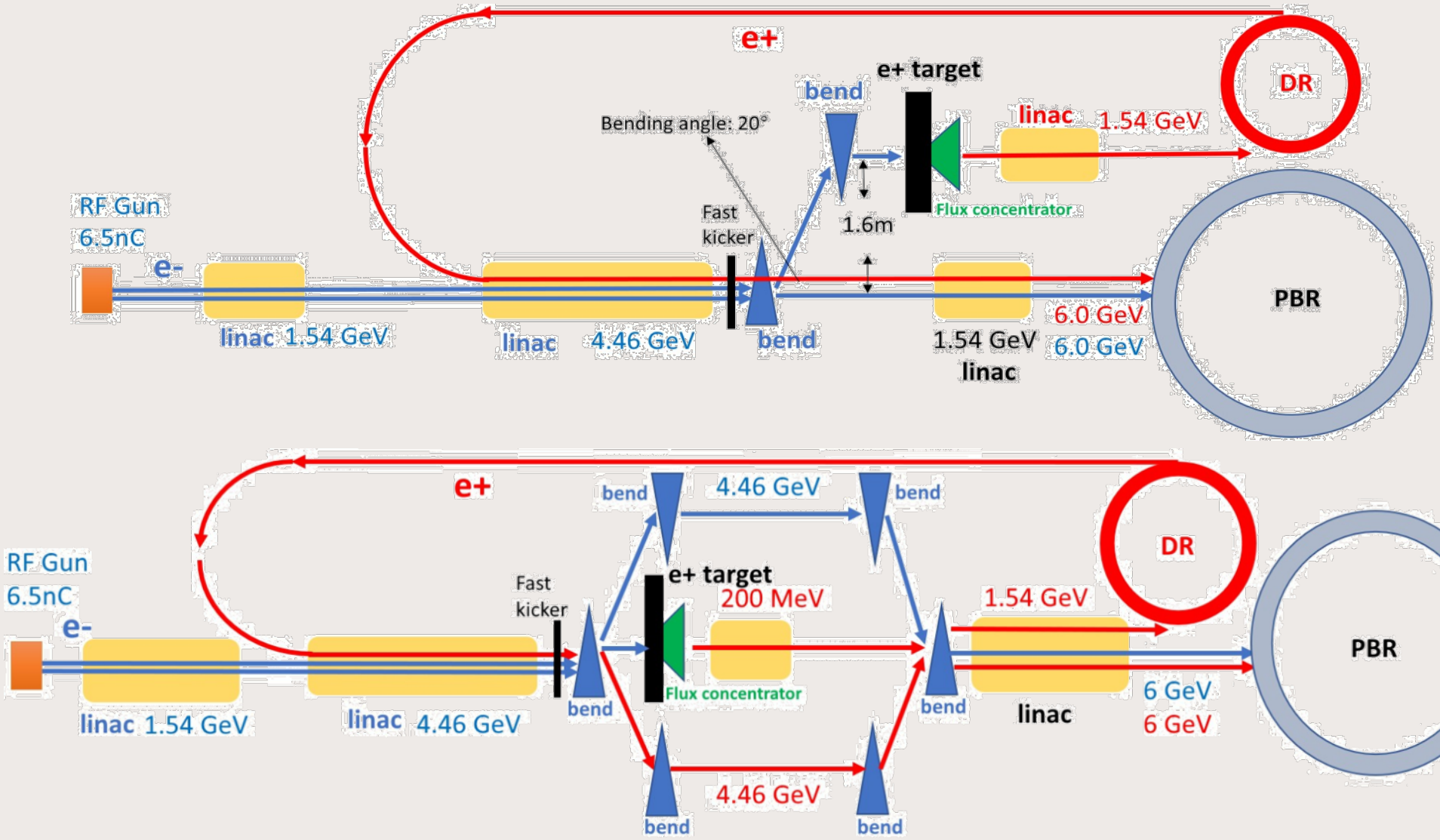
SuperKeKb injector linac







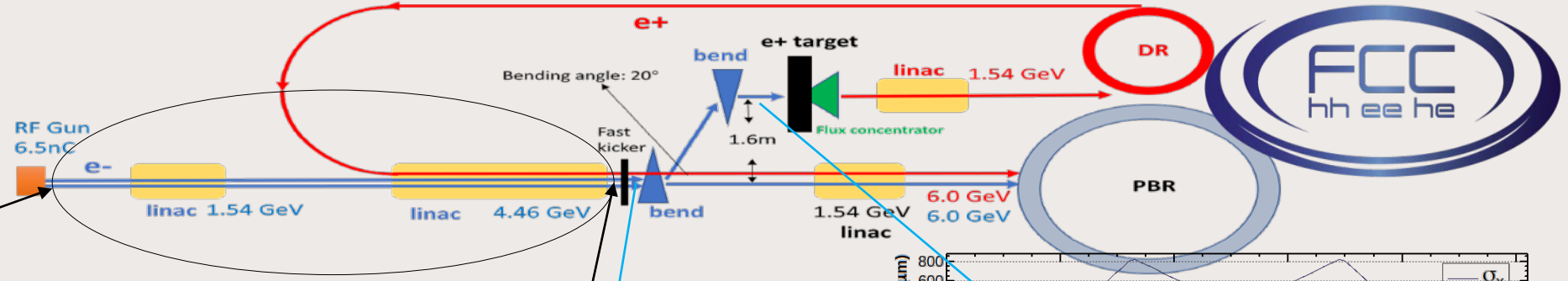
FCC-ee positron injector(bypass)



Dogleg

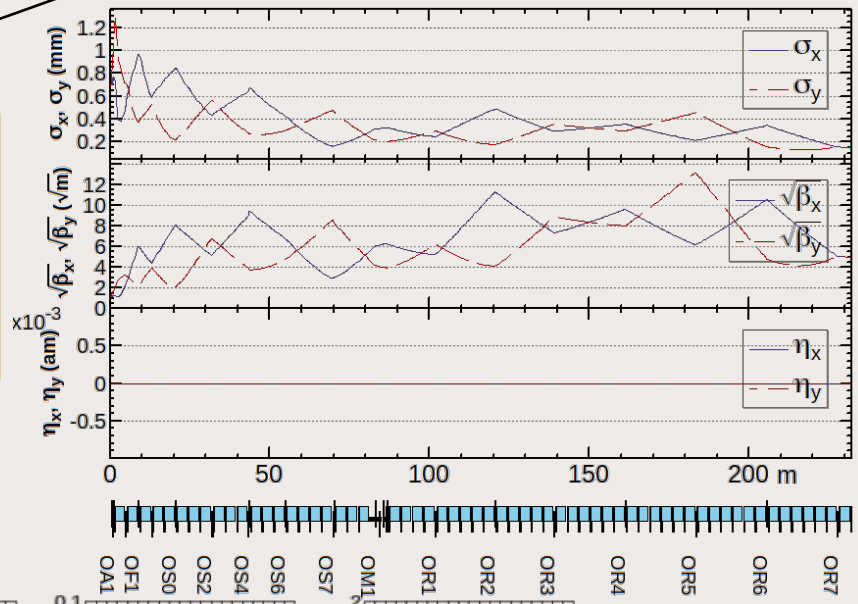
Chicane

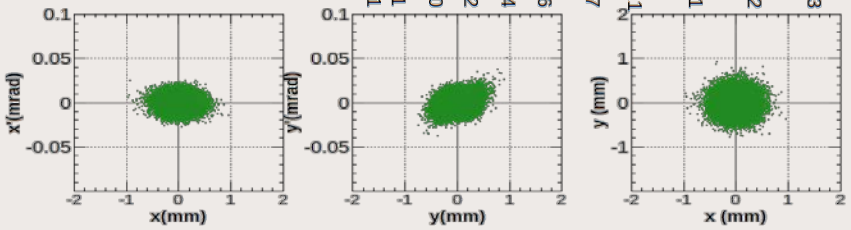
Dogleg bypass

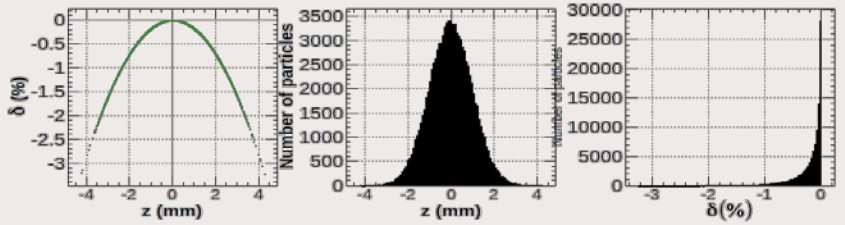


Simulation with SAD

e-
Start point:
E = 11 MeV
δE = 1%
Q = 3.5 nC
σ_z = 1mm
$\varepsilon_{x,y}$ = 0.35 um

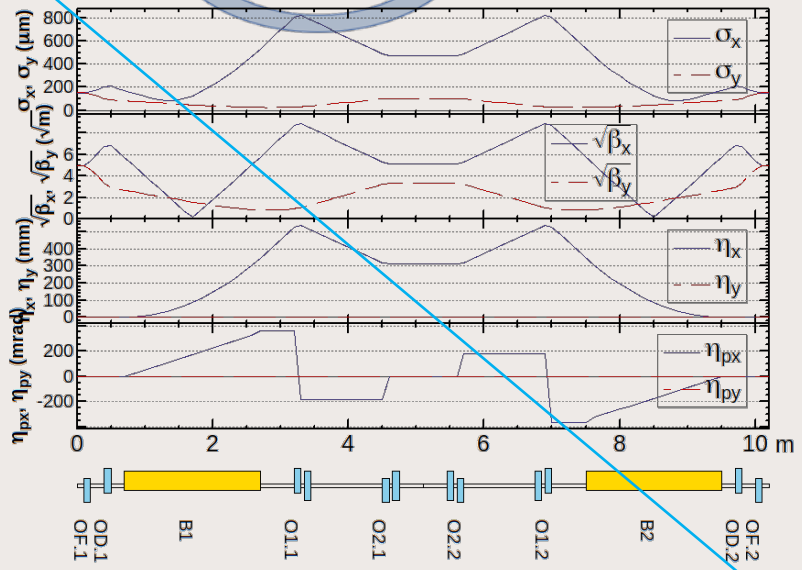




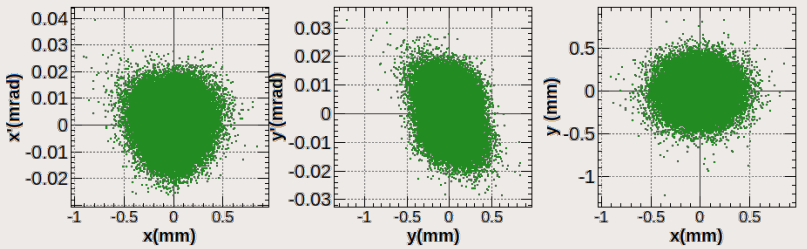


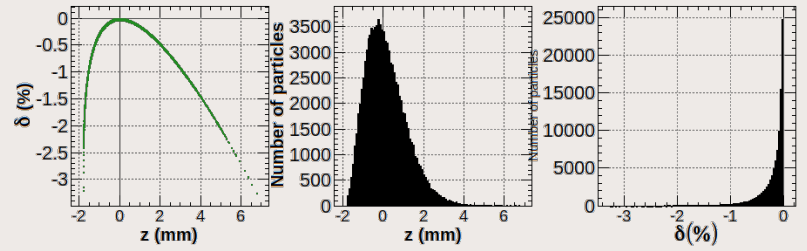
e-
End point:
E = 4.46 GeV
δE = 0.25%
Q = 3.5 nC
σ_z = 1mm
$\varepsilon_{x,y}$ = 9.4e − 10 m
σ_x = 152um
σ_z = 156um

e-
Start point:
E = 4.46 GeV
δE = 0.25%
Q = 3.5 nC
σ_z = 1mm
$\varepsilon_{x,y}$ = 9.4e − 10 m
σ_x = 152um
σ_z = 156um



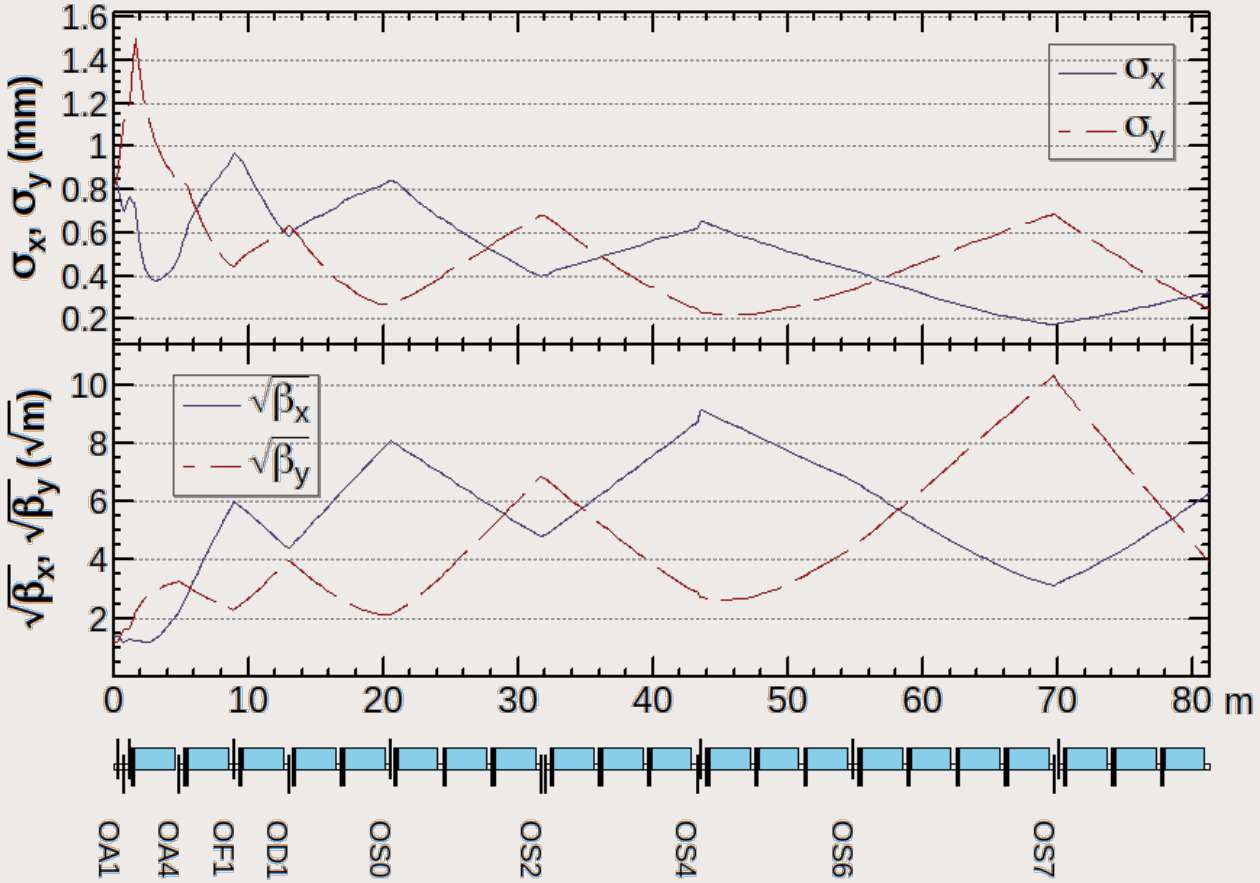
e-
End point:
E = 4.46 GeV
δE = 0.25%
Q = 3.5 nC
σ_z = 1mm
ε_x = 10.3e − 10 m
ε_y = 9.47e − 10 m
σ_x = 152 um
σ_z = 151 um

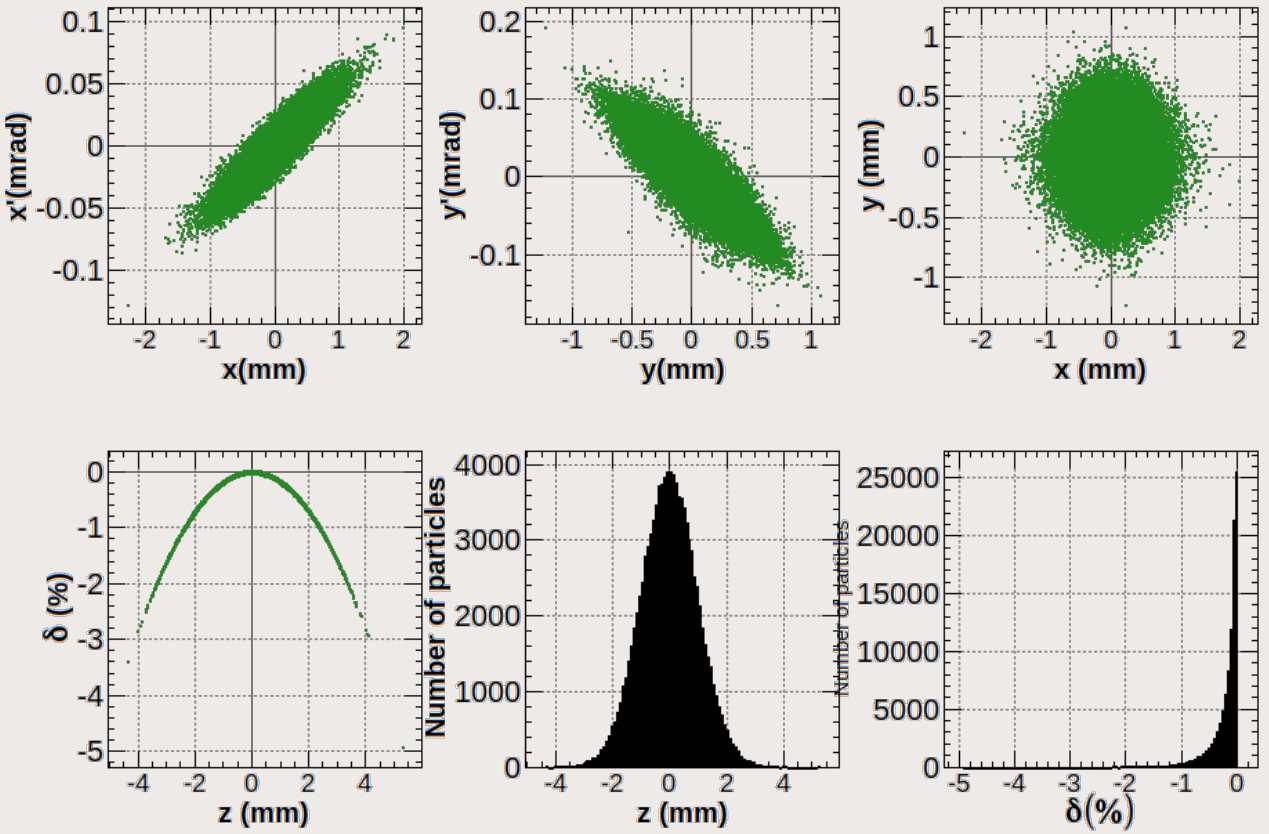




Positron linac

0 – 1.54GeV e- linac





αx = -2, αy = 2, βx = 39.52, βy = 15.56,
εx = 2.7e-9m, εy = 3.8e-9m, σx = 0.327 mm, σy = 0.243 mm
E = 1.571GeV, δE = 0.25%, σz : 1mm

Future work

- The dogleg bypass
  - Different angles studies to cope with target issues/hardware
  - Chromaticity correction and Coherent SR mitigation
- The chicane bypass
  - To be designed following a scheme similar to CEPC, but shorter length
- Positron linac design
  - Design of e+ linac from 200 MeV to 1.54 GeV
  - Start-to-end-simulations from (RF gun → DR) with Wakefield and BBU and CSR

Merci!!!