The Generation for Ultra Short Electron Beam from 47 MeV Linear Accelerator at PAL

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Outline

1. Introduction

2. Current performance of the existing test linac

3. Design study for the FIR Facility of the test linac

4. Summary

Introduction

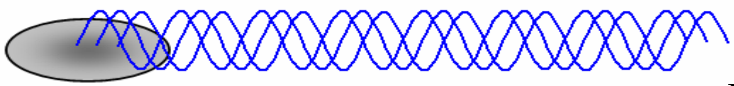
What's FIR (Far Infrared) radiation?

The electromagnetic radiation spectrum between wavelengths of 10 μm – 1000 μm

Why FIR radiation? **Few available source**

The molecule-surface-bond vibrations frequency range
Intermolecular cluster vibrations frequency range

Coherent radiation



Incoherent radiation $I \propto N$

Coherent radiation $I \propto N^2$

Why ultra-short bunches?

Femto-second Electron beam

Coherent FIR radiation

High-power infrared light sources by coherent radiation

⇒ **Provide powerful and effective tools to speed up existing experiments**

⇒ **Increase the accuracy of measurements**

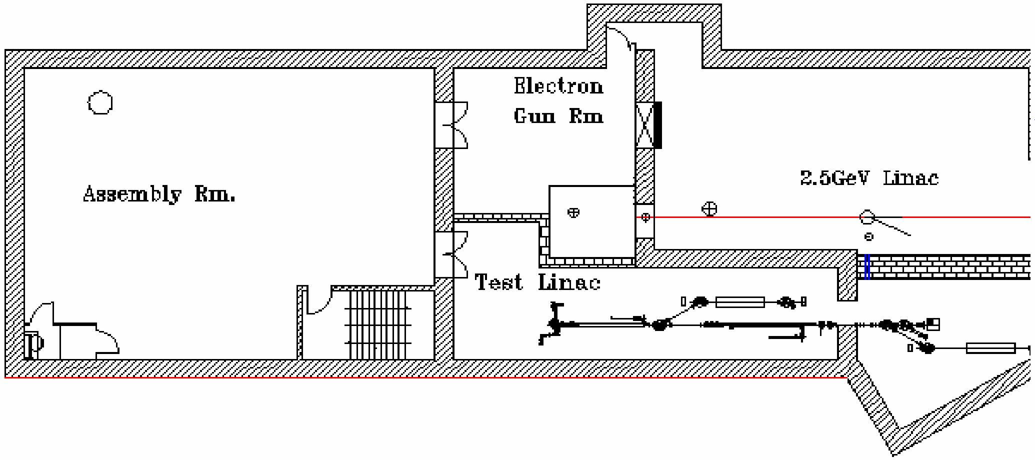
Pulsed radiolysis (time-resolved ultra-fast chemistry)

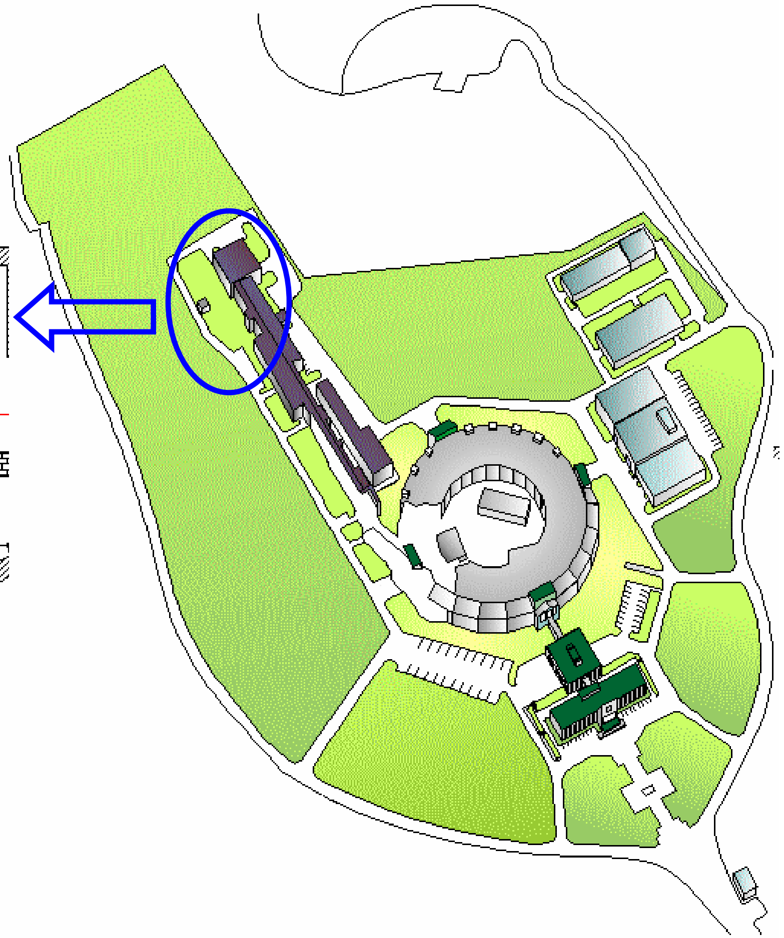
Generation of short electron beam with linear accelerator at PAL

1. Thermionic RF gun combined with an alpha magnet and RF linear accelerator
   --- by existing test linac

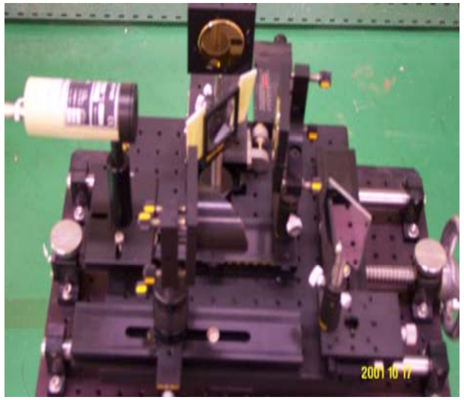
2. Photo-cathode RF gun combined with a magnetic chicane and an RF linear accelerator
   ---- by proposed a new linac

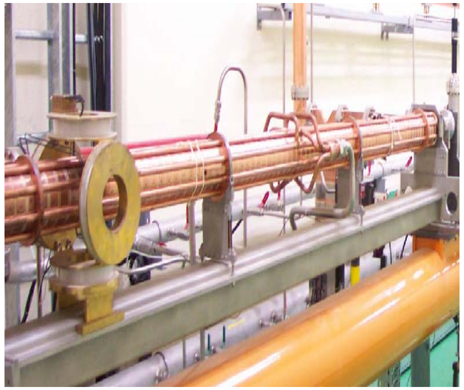
Current performance of the existing test linac

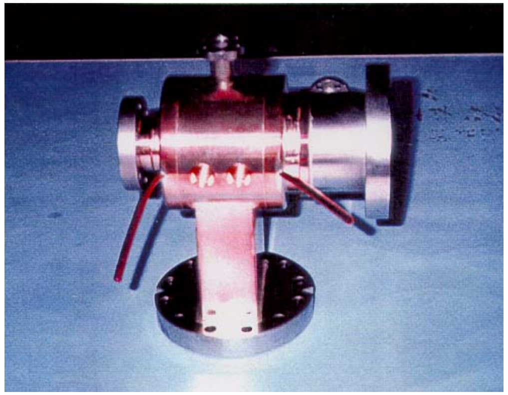




Components of the test linac







<u>Machine parameters</u>

⇒ Beam energy : 80 MeV

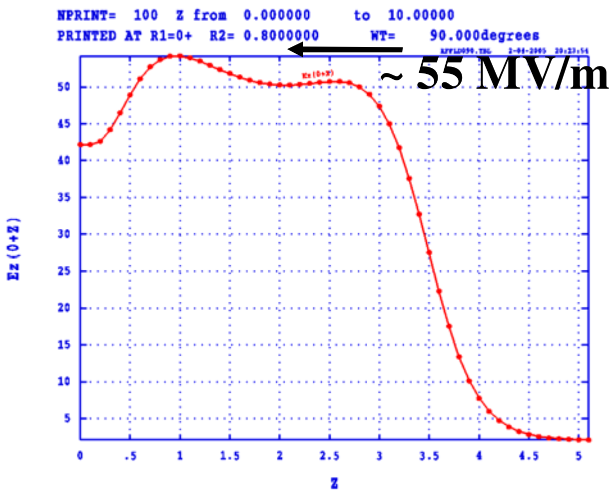
⇒ Beam current : 100 mA

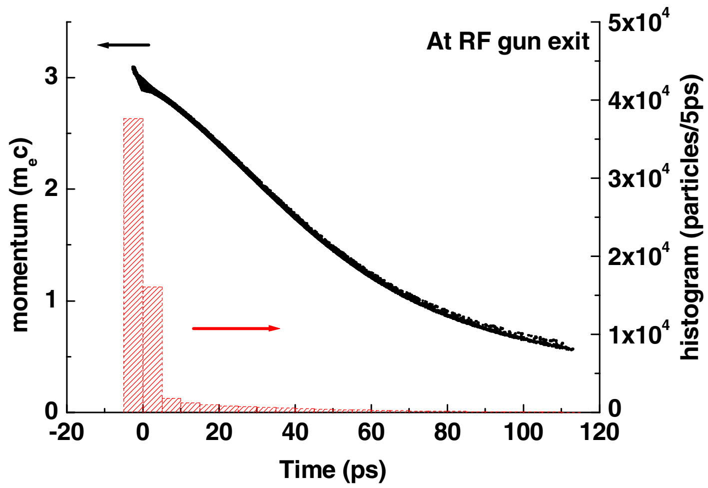
⇒ Pulse length : 3 μs/10 Hz

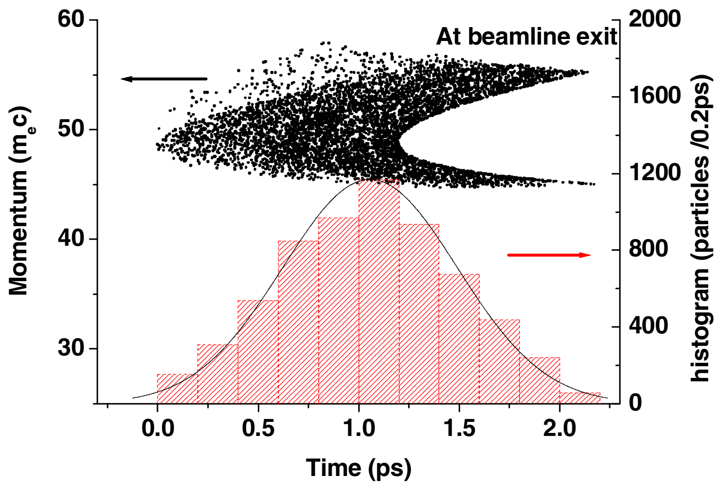
⇒ Energy spread : < 1 %

⇒ Beam Emittance : 30 μm rad

Beam parameters of existing test linac







RF-gun and beam parameters

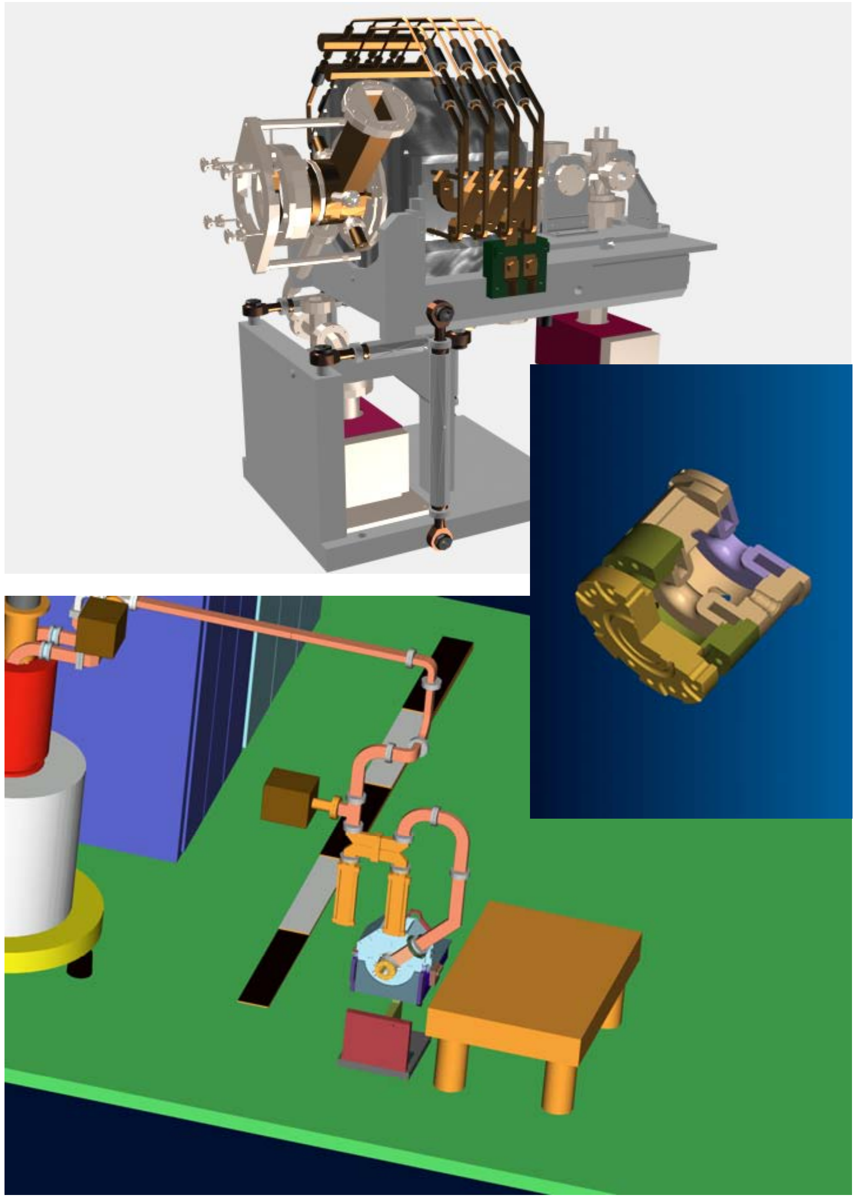
Max.beam energy at gun exit	1.2	MeV
RF-gun frequency	2856	MHz
Avg. field in half cell	33	MV/m
Cathode emission current	2.9	A
Beam energy	25	MeV
Charge/bunch	64	pC
Bunch length (rms)	400	fs

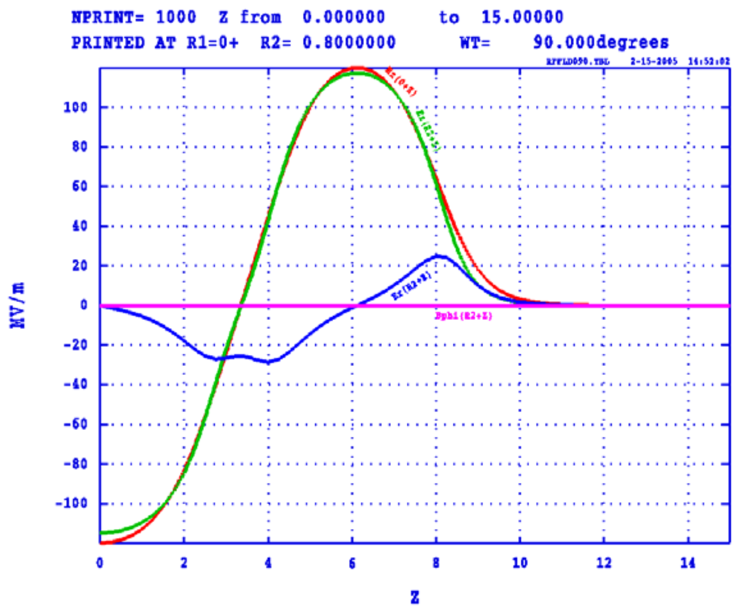
Needs for upgrade of test linac

Although thermionic RF gun is a good source for FIR radiation, pothocathode RF gun is more desired for FIR radiation due to higher beam quality.

These day, New FIR facility at PAL has been planed for fast chemistry experiment in user service.
: BNL type photocathode RF gun4 is being developed.

Photo-cathode RF gun [BNL-type gun IV]





Main parameters

laser

⇒ Max. pulse energy : 250 μJ (1nC)

⇒ Operating wavelength : 266 nm

photocathode

⇒ Q.E. : > 10^{-4}

⇒ Life time : > Weeks

⇒ Max. field : 120 MV/m

Design study for 47 MeV FIR Facility at PAL

consists of
photocathode RF GUN,
two accelerating sections and
a bunch compressor

The codes for simulation studies

PARMELA

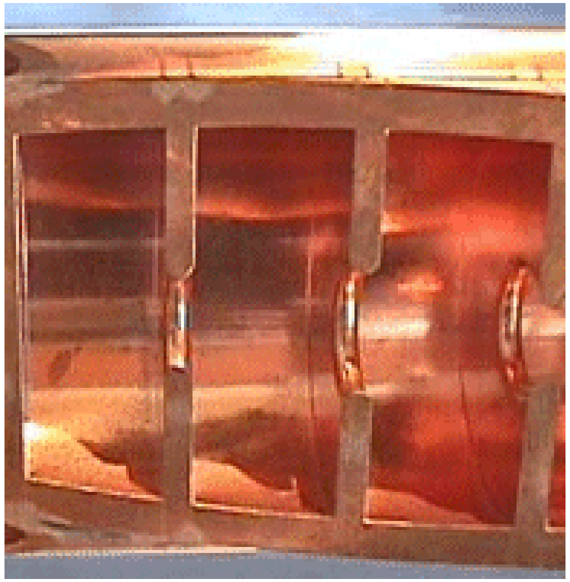
⇒ **PARMELA is a 3D particle tracking code to simulate the dynamics in rf guns and beam line elements.**

ELEGANT

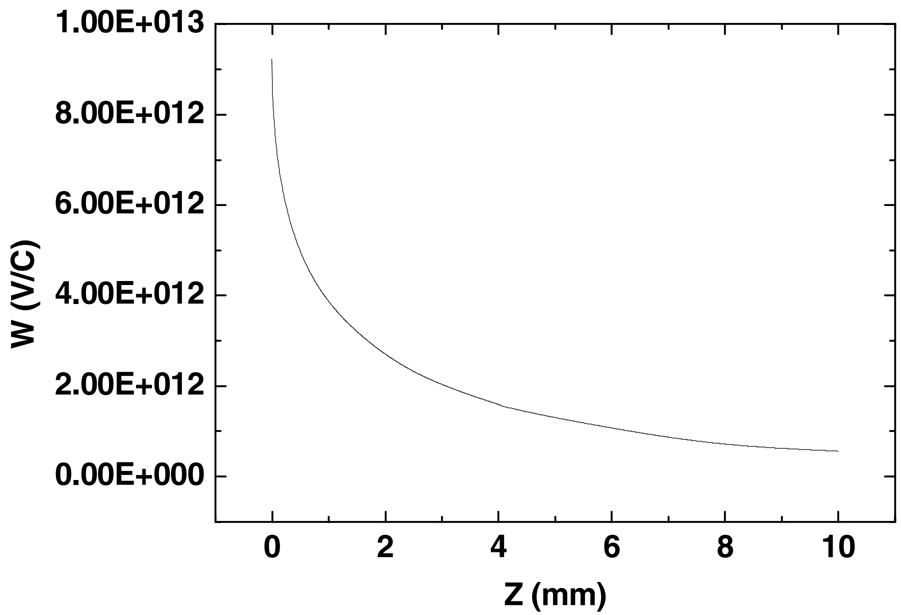
⇒ **Elegant is a multi-purpose 3D particle tracking code through a linear accelerator. Although it excludes space charge, Elegant has an analytical model for the coherent synchrotron radiation in a bending system and its interaction on the beam.**

Effect	PARMELA	ELEGANT
Space charge effect	○	×
Wake field effect	×	○
CSR wake effect	×	○

Geometrical wake



Accelerator structure



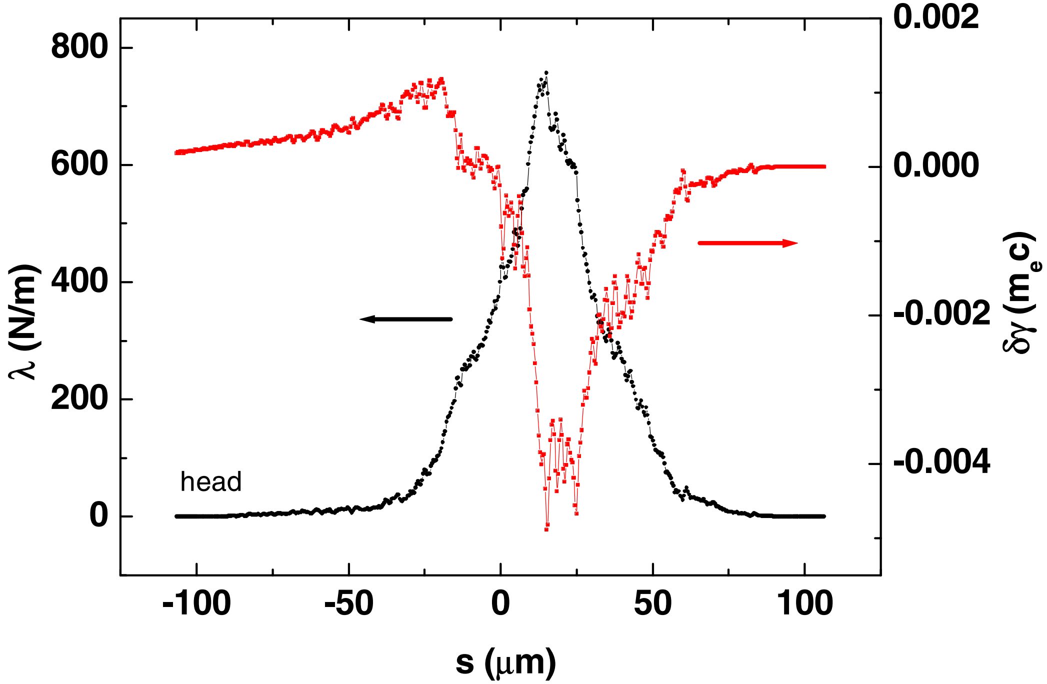
Longitudinal wake field

Energy change by longitudinal wake field

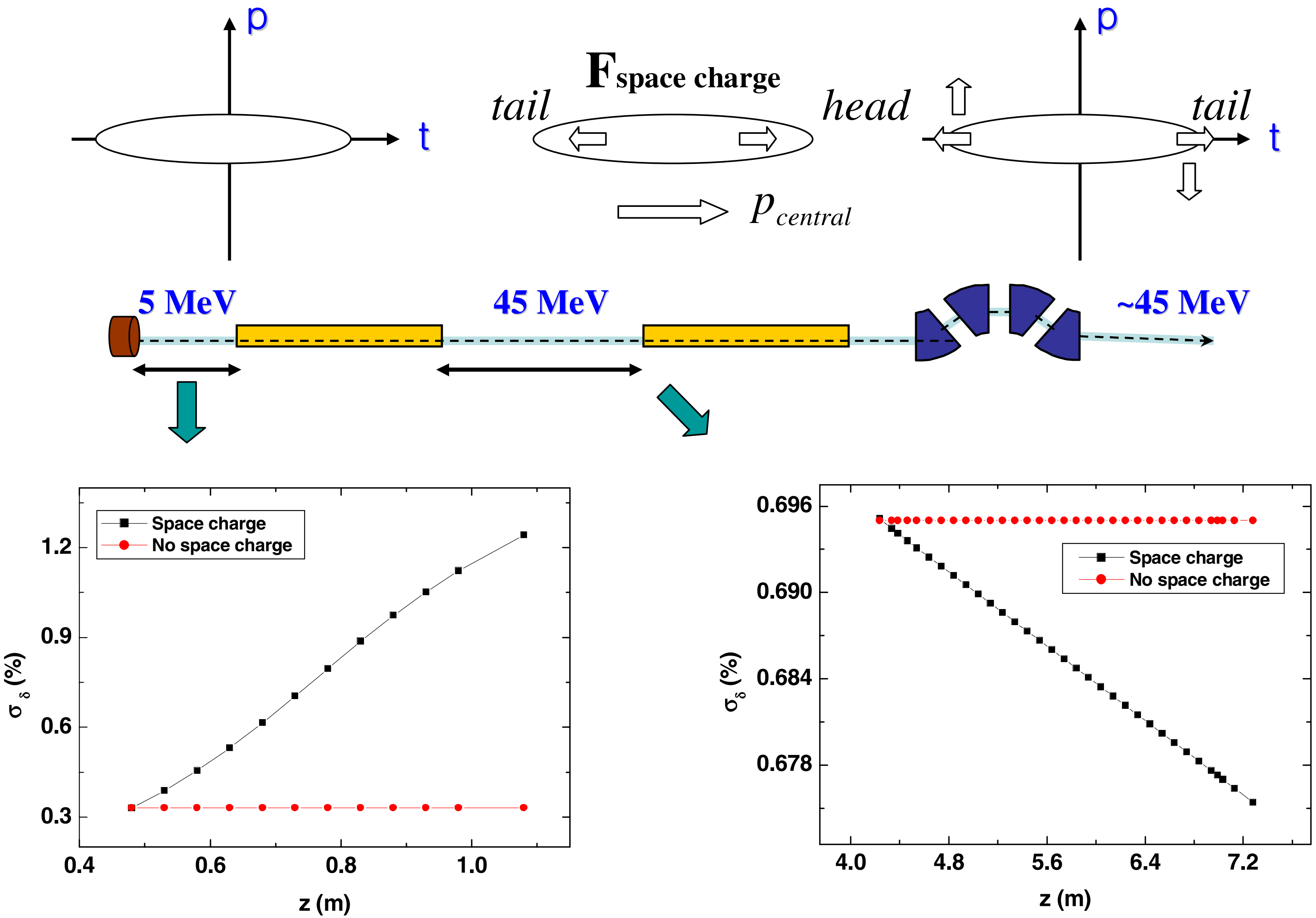
$$\Delta U = -\int_{z(tail)}^{z(head)} e\lambda(z')dz' \underbrace{\int_{z'}^{z(head)} e\lambda(z)W(z-z')dz}_{\text{Wake potential at } z'}$$

CSR wake

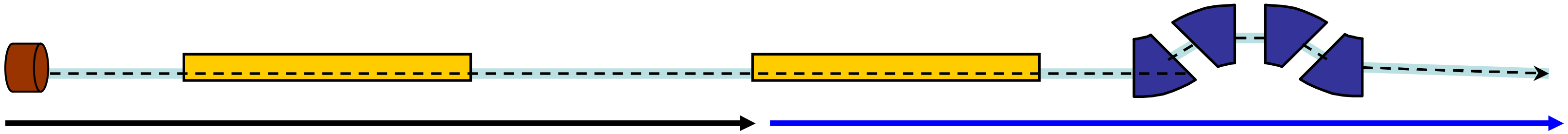
$$\frac{dE(s,\phi)}{cdt} = \frac{-2e^2}{(3R^2)^{1/3}} \int_{s-R\phi^3/24}^{s} \frac{d\lambda}{dz} \left(\frac{1}{s-z}\right)^{1/3} dz \; - \frac{2e^2}{(3R^2)^{1/3}} \left(\frac{24}{R\phi^3}\right)^{1/3} [\lambda(s-R\phi^3/24) - \lambda(s-R\phi^3/6)]$$



Space charge force

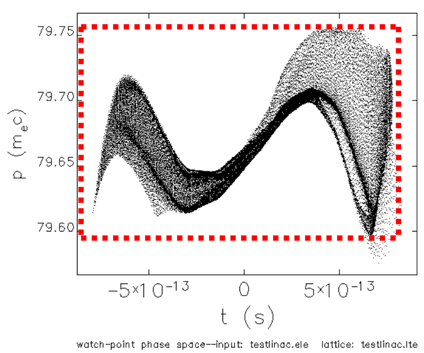


Simulation results I (PARMELA +ELEGANT)

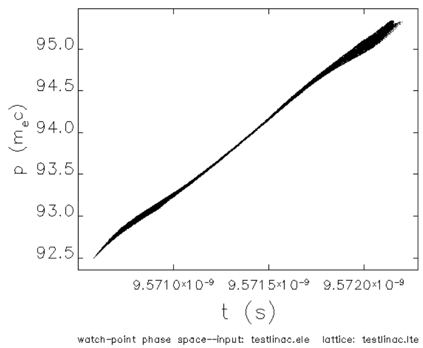


PARMELA space charge (○),wakes (×) **ELEGANT space charge (×),wakes (○)**

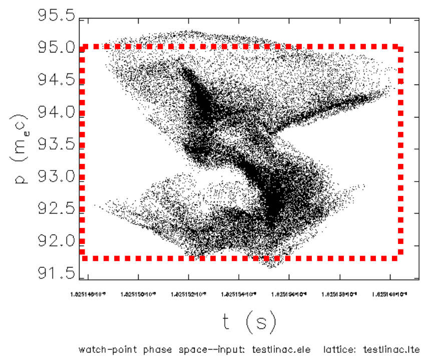
Longitudinal particle distribution



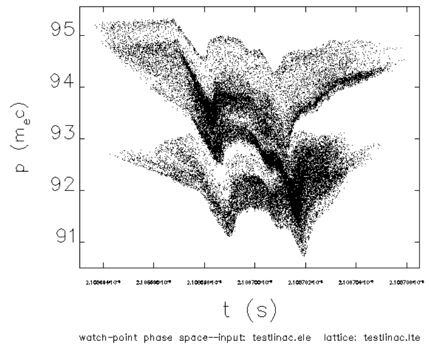
After first linac



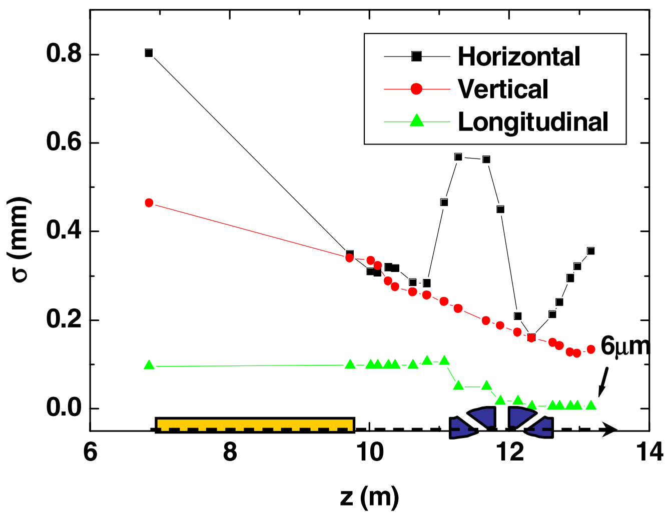
After second linac



After chicane

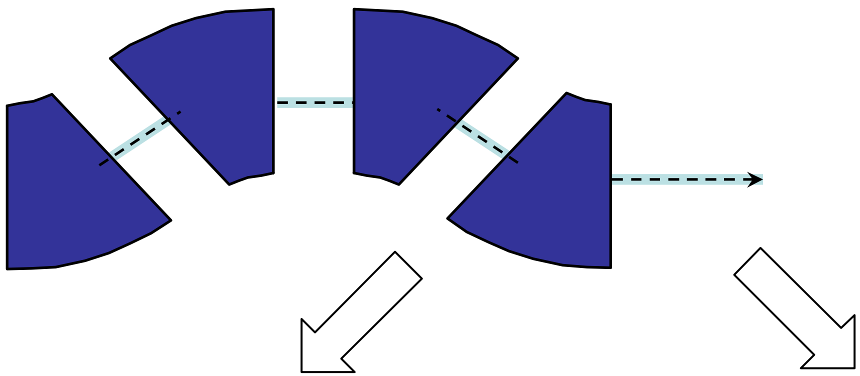


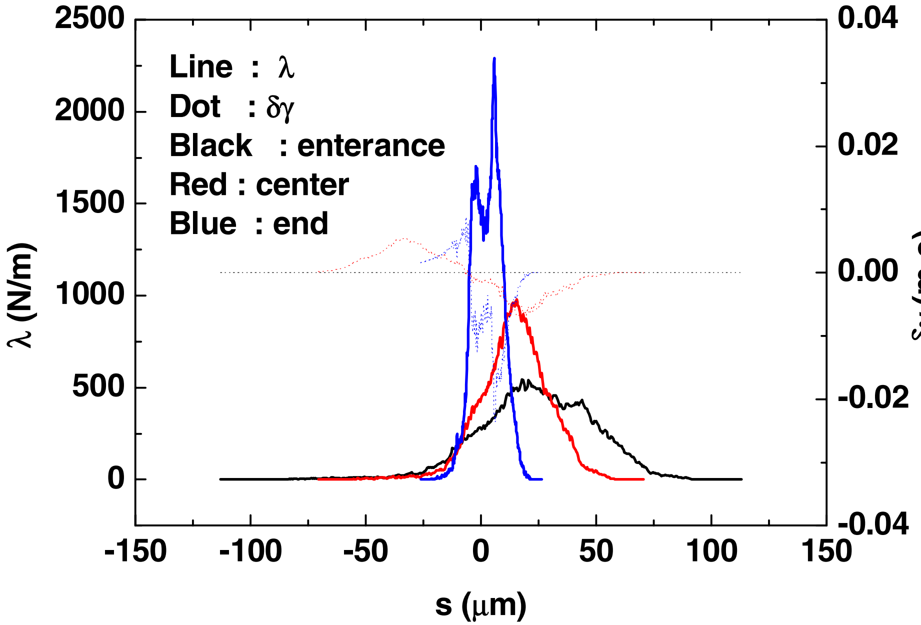
At the target



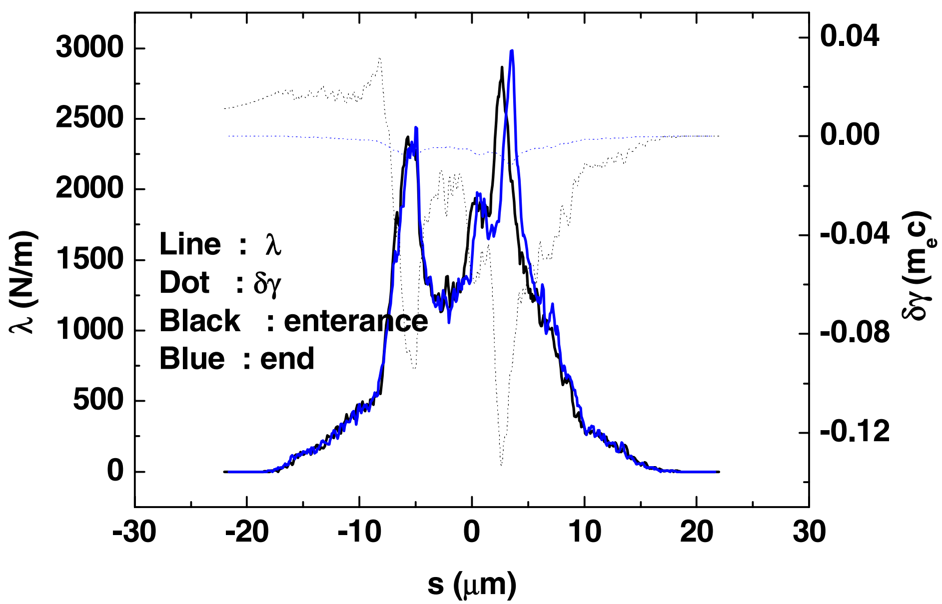
PARAMETER	VALUE	UNIT
Field of the accelerator I	14	MV/m
Phase of the accelerator I	89	Degree
Field of the accelerator II	17	MV/m
Phase of the accelerator II	8.15	Degree
R56	-13.8	mm

CSR wake effect in a chicane



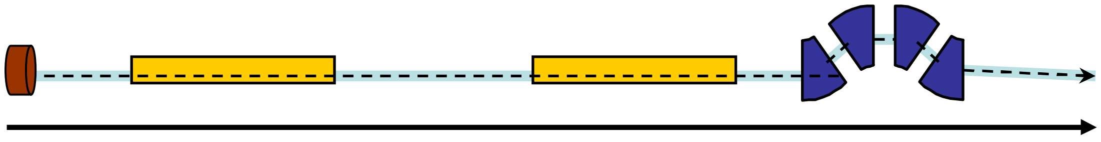


Dipole 4



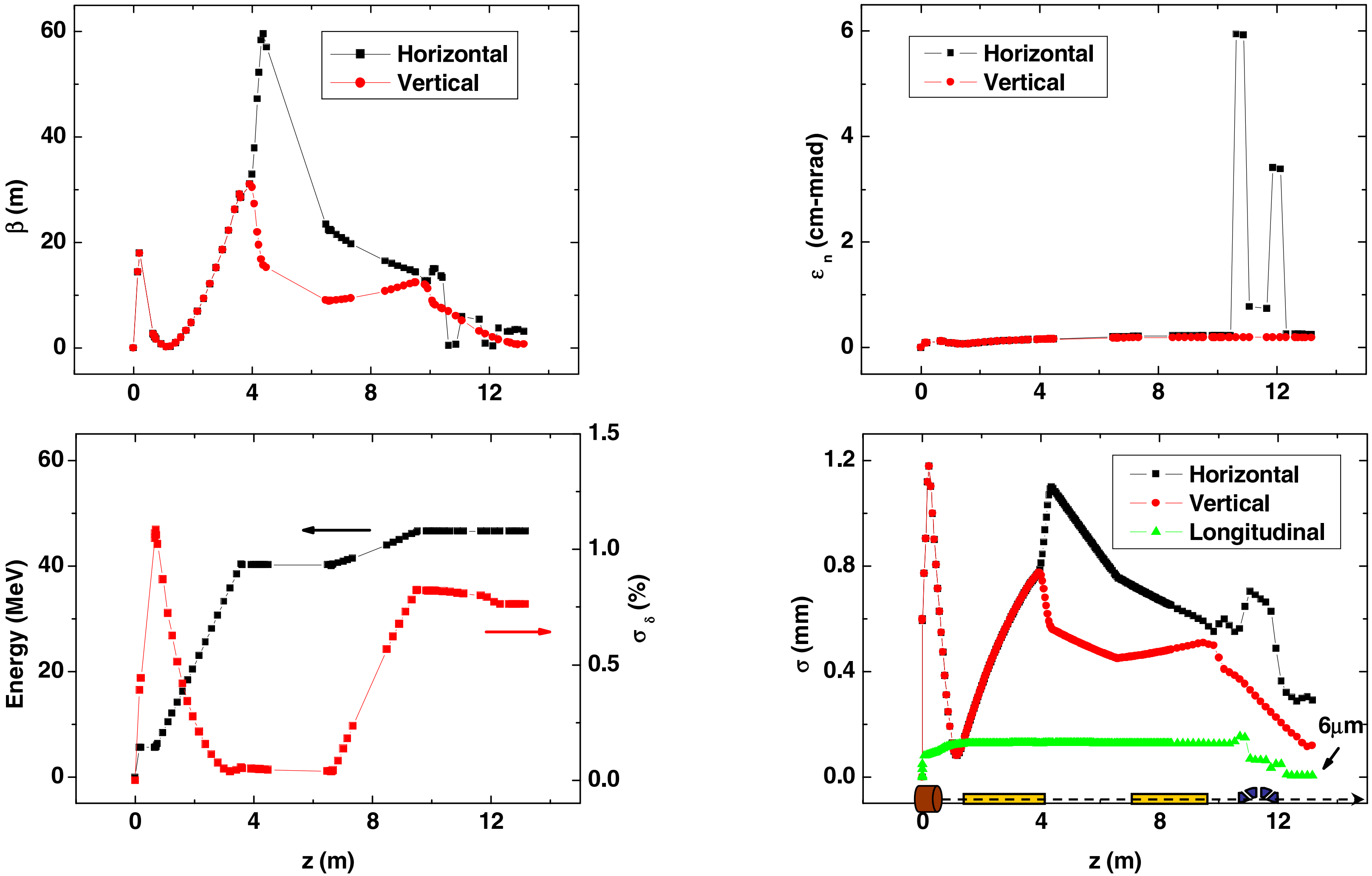
Drift space after dipole 4

Simulation results II (PARMELA)



PARMELA

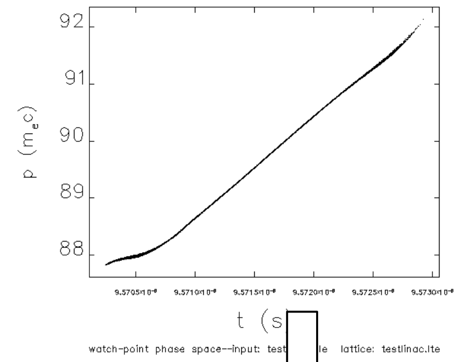
space charge (○), wake (×)

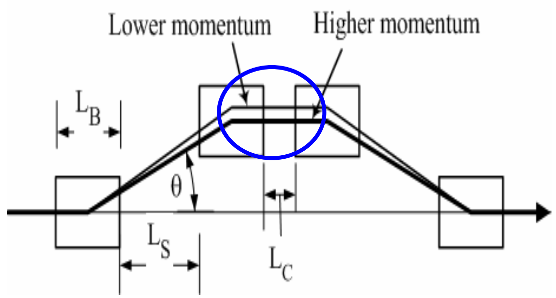


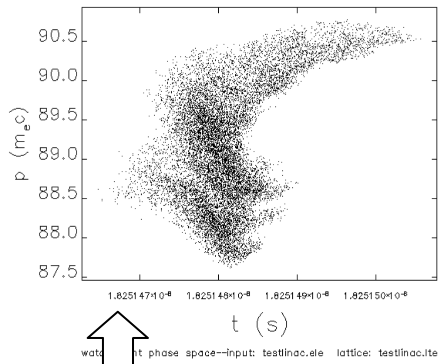
Comparison results

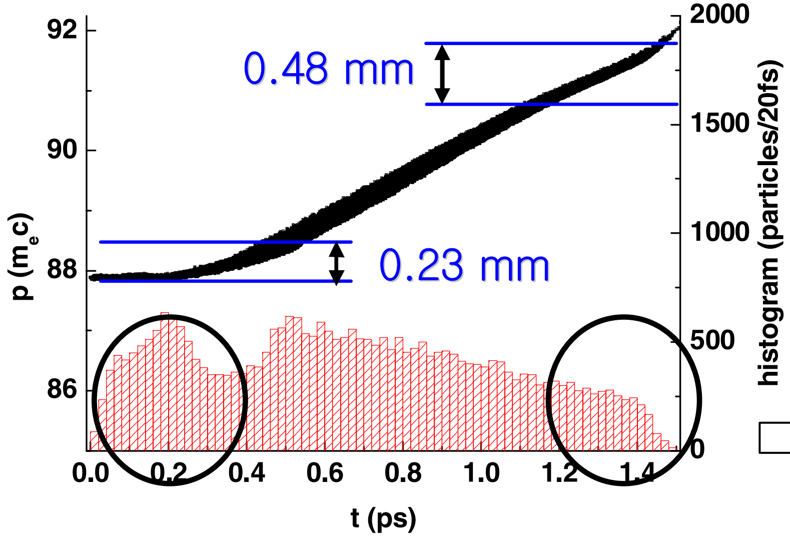
Parameter	Simulation2 PARMELA	Simulation1 PARMELA + ELEGANT	
		(CSR turn off)	(CSR turn on)
ε_{nx} (cm-mrad)	0.25	0.2	0.328
ε_{nx} (cm-mrad)	0.19	0.18	0.18
σ_x (mm)	0.29	0.23	0.356
σ_y (mm)	0.12	0.14	0.133
σ_t (fs) (σ_{ti}=300fs)	21	18	20
Beam energy (MeV)	~ 47 MeV	~ 47 MeV	~ 47 MeV
Energy spread	0.0076	0.0077	0.01
Charge / bunch (nC)	0.1	0.1	0.1

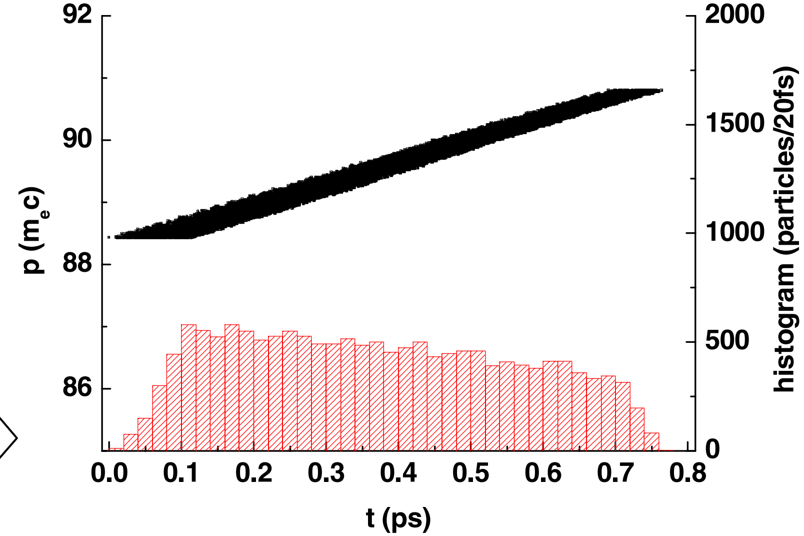
Using energy slit in a chicane (Simulation I)











Before slit

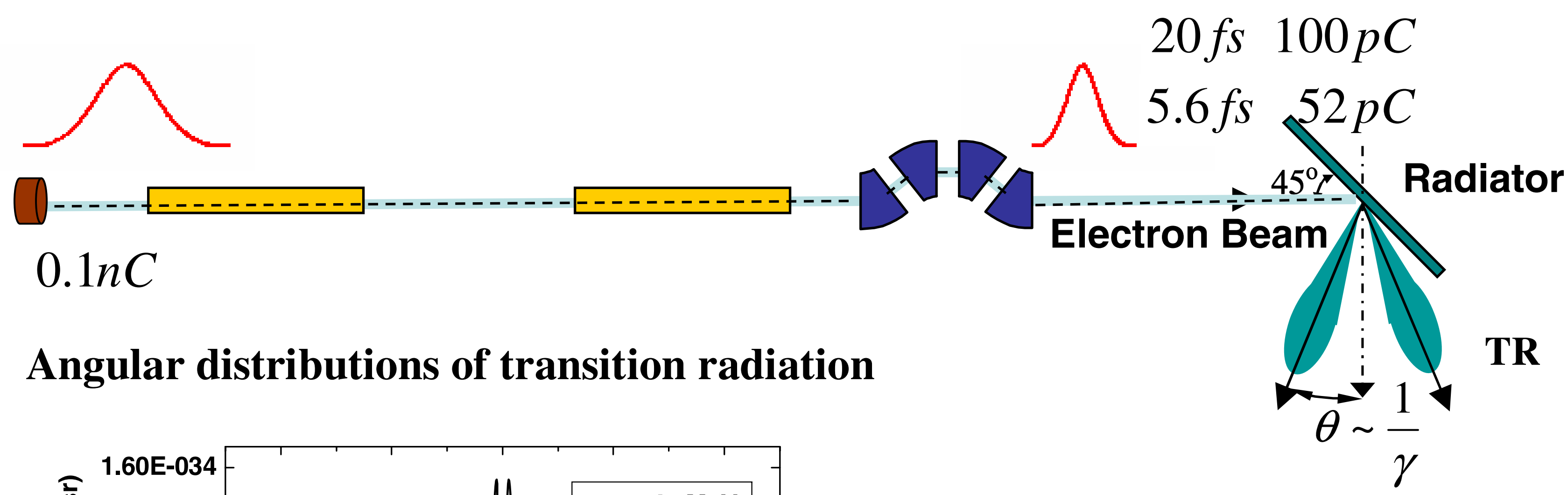
52% transmission

After slit

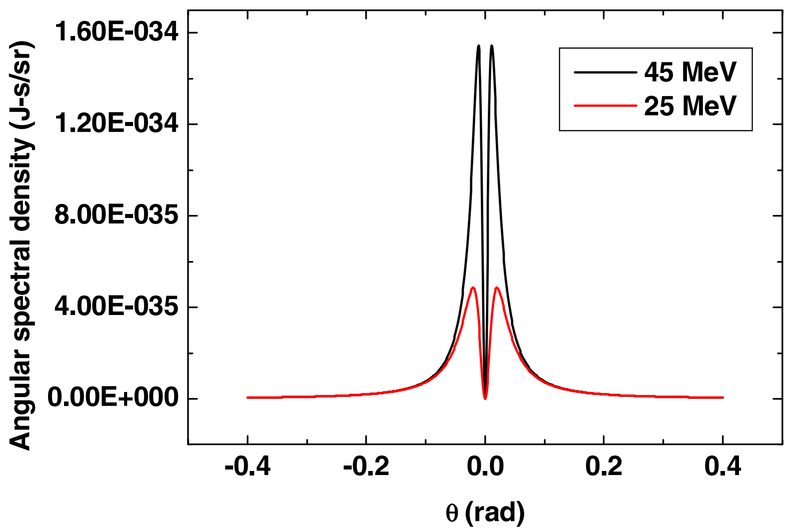
Results

⇒ **Charge : 52 pC** σ_z **: 5.6 fs**

Transition radiation



Angular distributions of transition radiation



Angular distributions of normal incident transition radiation generated by 25 MeV and 45 MeV electrons.

Radiated energy

$$W_{tot}[J] \approx 3.6\times10^{-2}(Q[nC]^2)\ln(\gamma)/\lambda\min[\mu m]$$

$$\gamma = 90(47MeV) \qquad Q[nC] = 0.1$$

$$\lambda\min \approx \sigma_z = 6\mu m$$

$$\Rightarrow W_{tot} \approx 270\mu J$$

Comparison between PLS SR and FIR-TR

Synchrotron radiation

Beam energy : 2.5 GeV

Beam current : 150 mA (average)

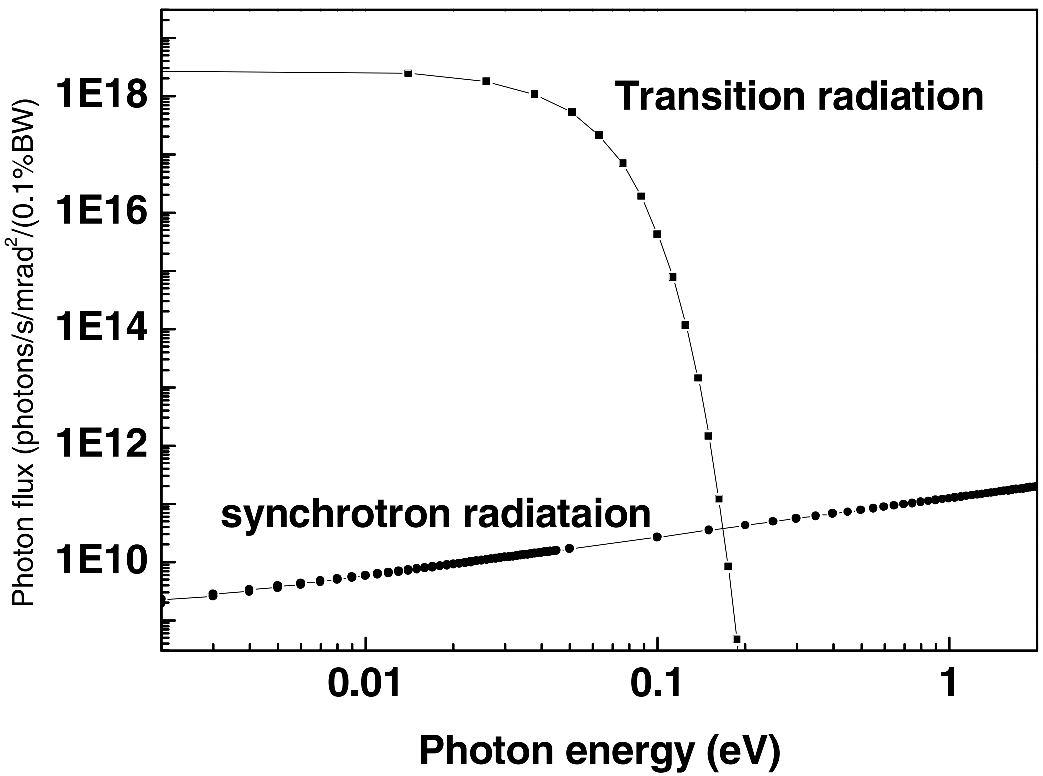
Beam size : 32 ps (longitudinal)

Transition radiation

Beam energy : 47 MeV

Beam current : 960 A (peak)

Beam size : 6 μm (longitudinal)



SUMMARY

1. It is shown that existing test linc at PAL can produce 400 fs rms bunch length with bunch charge of 64 pC.
2. Through the design studies, it was shown that new FIR facility can produce the beam with bunch length of 20 fs rms, bunch charge of 0.1 nC and energy of 270 µJ per pulse.
3. Using an energy slit in the chicane, we can obtain beam with 5.6 fs rms bunch length, bunch charge of 52 pC and 260 µJ per pulse.
4. It is shown that obtained beam parameters satisfy user's demand for FIR facility.