Optics and Beam Collimation for ILC e+ Source

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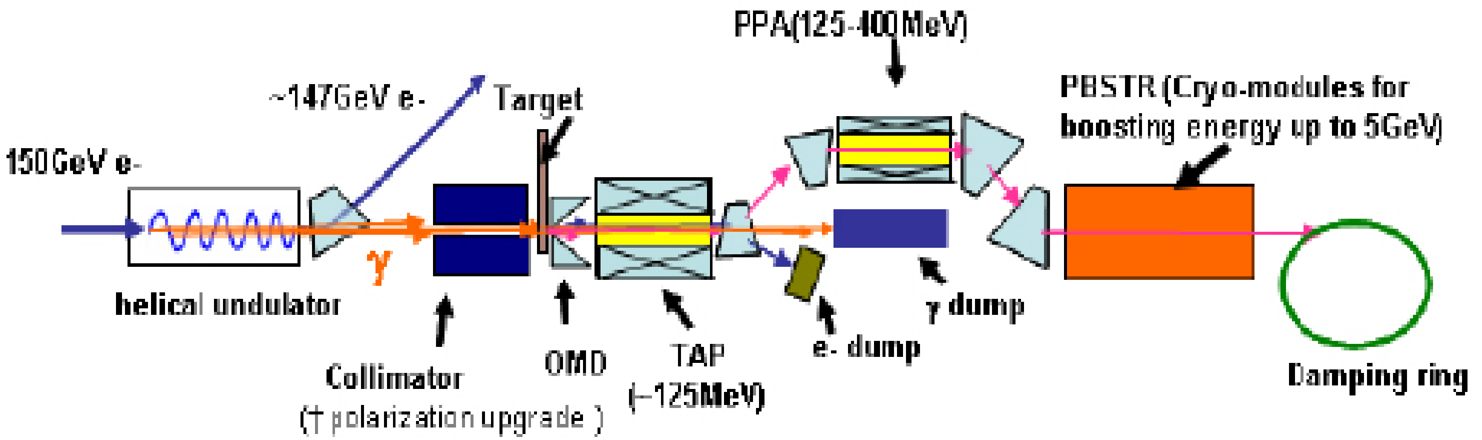
Optics overview



- 150 GeV e- insert chicane: see http://www.slac.stanford.edu/~yuri/
- Target to capture system (125 MeV)
- Target hall: 125 MeV dogleg,125-400 MeV NC pre-acceleration, and 400 MeV dogleg
- 5.03 km 400 MeV transport from e- main linac to e+ booster linac
- SC boost linac to 5 GeV
- Linac-to-Ring: spin rotations, energy compression, and beam collimation.

Chicane: Upgrade to 1 TeV?

Synchrotron radiation issues in the undulator chicane

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04/24/07

The energy loss per particle from synchrotron radiation is given by:

$$\Delta E = \frac{2}{3}\frac{r_e E^4}{(m_e c^2)^3} I_2 = 1.399\times10^{-5} E^4 I_2 \text{ (GeV)}$$

Where the r_e is the classical electron radius of 2.8×10^{-15}, E is in GeV, and I_2 is the second synchrotron radiation integral, $I_2 = \int \frac{ds}{\rho^2}$ in unit of 1/m.

Synchrotron radiation induced emittance growth is:

$$\Delta\gamma\varepsilon_x = \frac{55\cdot r_e\cdot\hbar c}{48\sqrt{3}mc^2}\gamma^6 \oint \frac{H}{|\rho^3|}ds$$

Where $\frac{55\cdot r_e\cdot\hbar c}{48\sqrt{3}mc^2} = 7.1529\times10^{-28}$, and $H = \gamma_x\eta_x^2 + 2\alpha_x\eta_x\eta_x' + \beta_x\eta_x'^2$, $\oint \frac{H}{|\rho^3|}ds = I_5$ is radiation integral. It can be rewritten as:

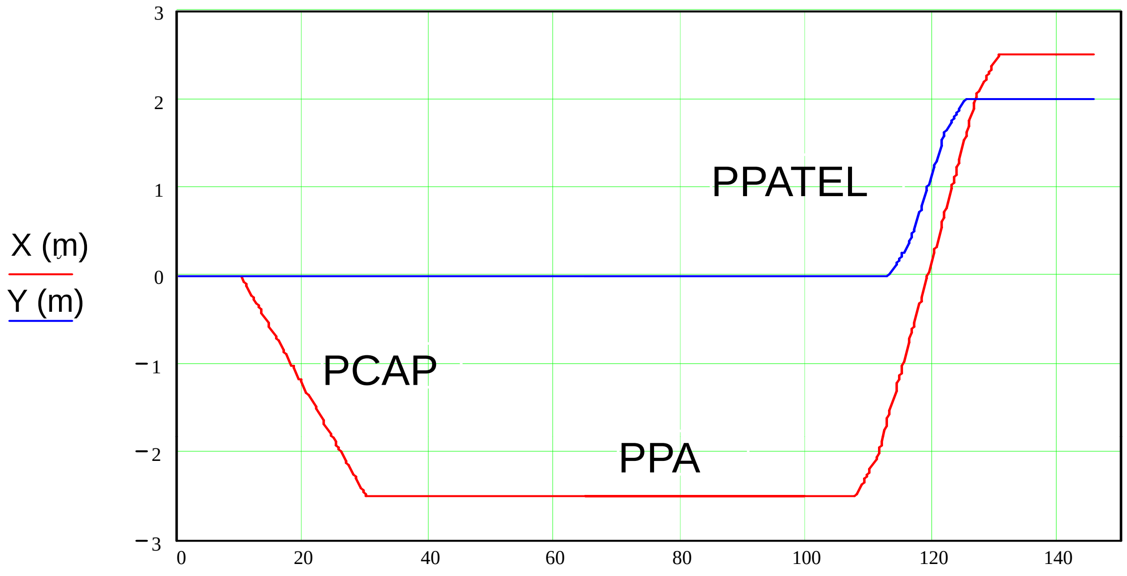
$$\Delta\gamma\varepsilon_x = 40.43 E^6 I_5 \text{ (nm)}$$

Based on YuriN's lattice, for each undulator arc, $I_2=1.2578\times10^{-5}$ (1/m) and $I_5=1.1746\times10^{-13}$ (1/m). At 150 GeV, the energy loss is 89.1 MeV (0.059%), and normalized emittance growth is 53.75 nm (1.79% increase for initial normalized horizontal emittance of 3e-6m). When the machine is upgraded to 1TeV, the electron beam energy passing through the undulator chicane will become 400 GeV. At 400 GeV, assume all geometry and Twiss parameters are not changed, same as the ones at 150 GeV, then synchrotron radiation integrals at 400 GeV should be same as at 150 GeV. The energy loss becomes 4.506 GeV (1.13%), and the normalized emittance growth is increased to 19452 nm (648.4%). It looks the optics has to be modified to reduce I_5 to suppress emittance growth for both the energy.

Note that the above results should multiply by 2 for two arcs.

Transport in target hall

- **Capture optics** – OMD, and capture cavities embedded in a 0.5 T of solenoid to accelerate e+ to 125 MeV.
- **PCAP** – 125 MeV e+ beam dogleg: to separate e+ from e- and photons using a dogleg.
- **PPA** – NC pre-accelerator embedded in a 0.5 T of solenoid to accelerate e+ to 400 MeV.
- **PPATEL** – 400-MeV horiz. and vert. dogleg to deflect the beam by 5 m and 2 m in the horiz. and vert. planes.



LTR – Linac to Ring

- **Spin rotations to preserve polarization in DR:**
  - Bending magnets from longitudinal to horizontal plane

$$\theta_{spin\_bend} = \frac{E(GeV)}{0.44065} \cdot \theta_{bend}$$

θ_{bend} = $n \cdot 7.929°$ at 5-GeV; here n=7 to get R56=86cm.

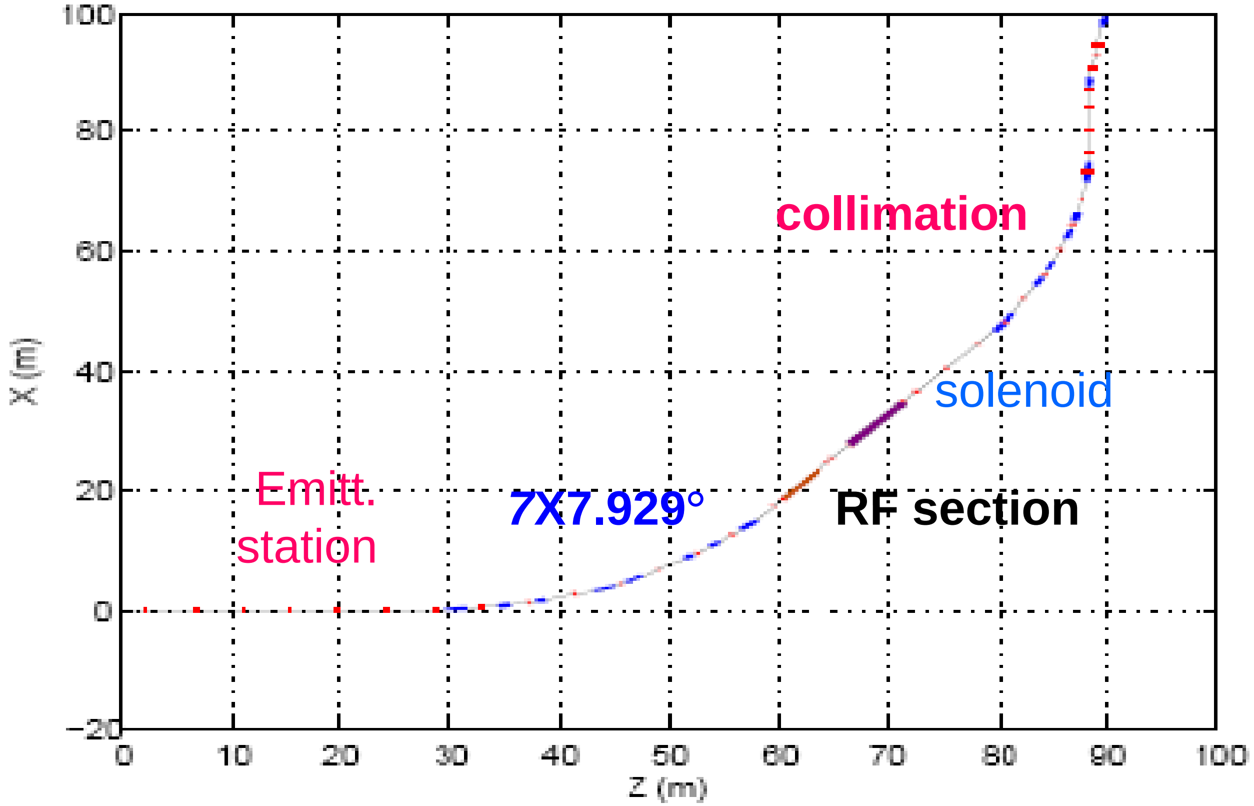
  - Solenoid from horiz. to vert., parallel to the magnetic field in DR.

$$\theta_{spin\_sole} \approx \frac{B_z \cdot L_{sole}}{B\rho}$$

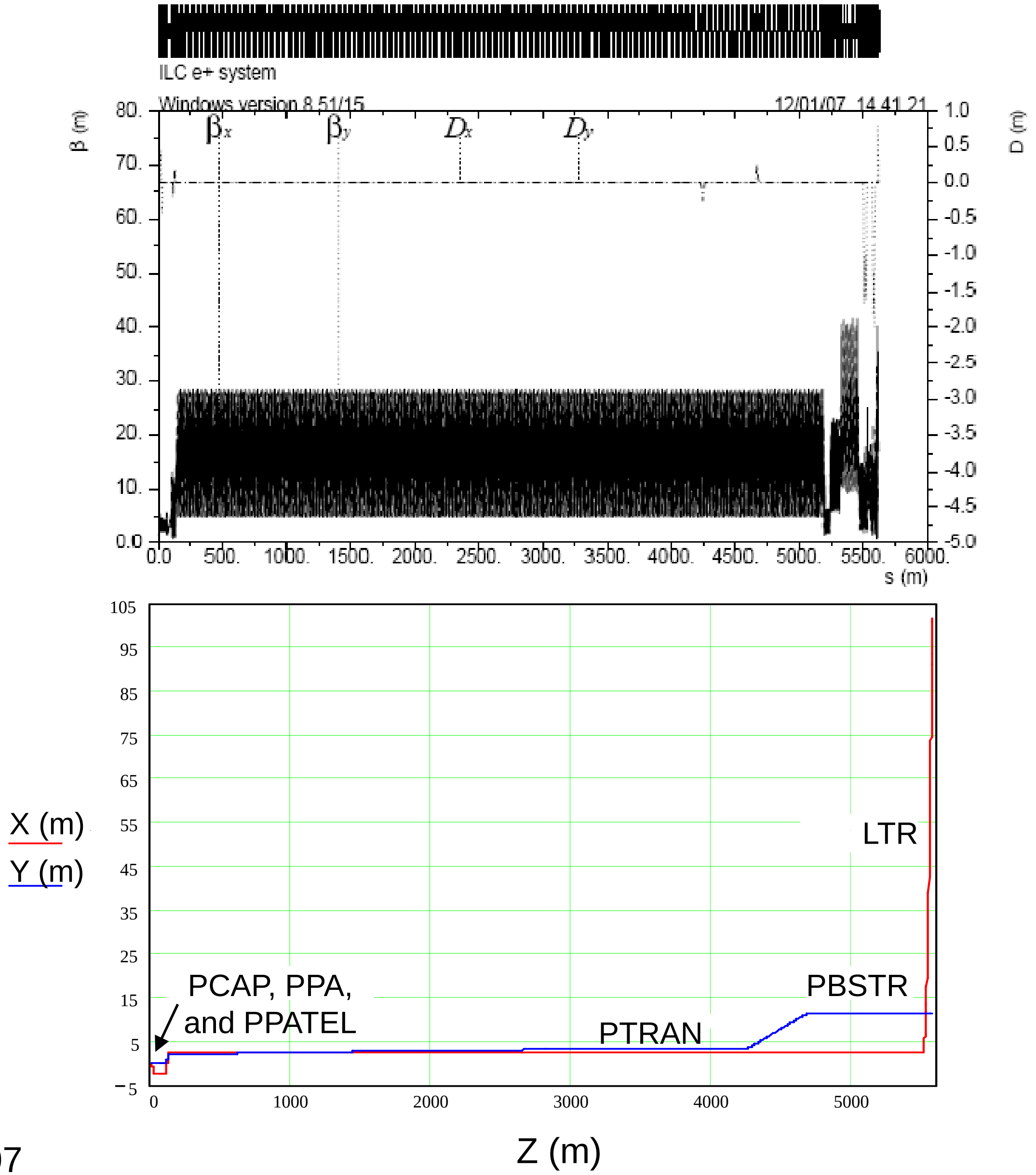
$B_z \times L_{sole}$ = 26.23 T.m at 5-GeV.

- **Energy compression:** R56 and RF section
- **Collimations**: to reduce e+ beyond the DR longitudinal acceptance.
- **Emittance measurement, and 3 PPS stoppers**
- **Matching section**

LTR geometry



Overall e+ source optics



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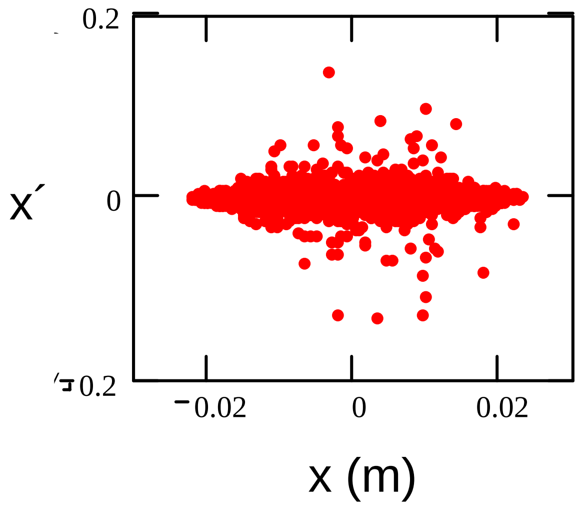
Collimation system

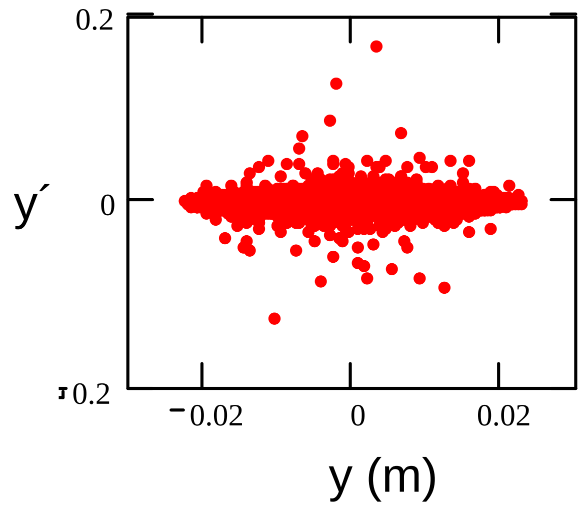
- Without the collimation system:
  - E+ will be lost in the beamline, and the power loss may severely exceeds the acceptable level, due to the extreme large energy spread and divergence in the beginning of the transport.
  - E+ power loss in the DR will be significant
- With the collimation system:
  - To control beam power loss in the beamline within 100 W/m and 1W/m for NC and SC elements, respectively.
  - To reduce power loss in the DR; to collimate positrons beyond DR 6-D acceptance before injecting into DR:

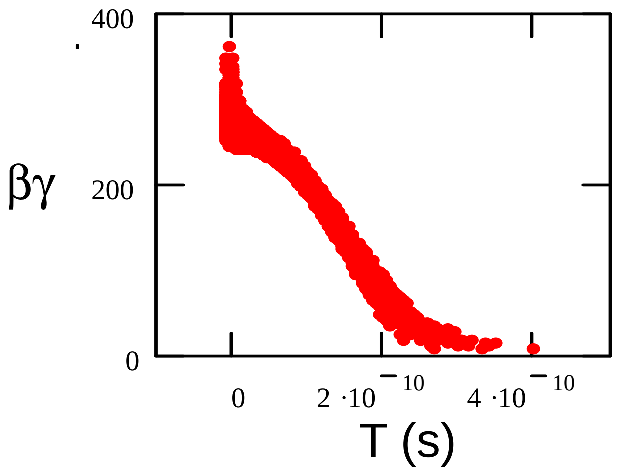
$$A_x + A_y \leq 0.09\text{m}$$

$$\Delta E \times \Delta z \leq (\pm 25\text{MeV}) \times (\pm 3.46\text{cm})$$

Input 6-D phase spaces at 125 MeV







Courtesy of
Wanming Liu

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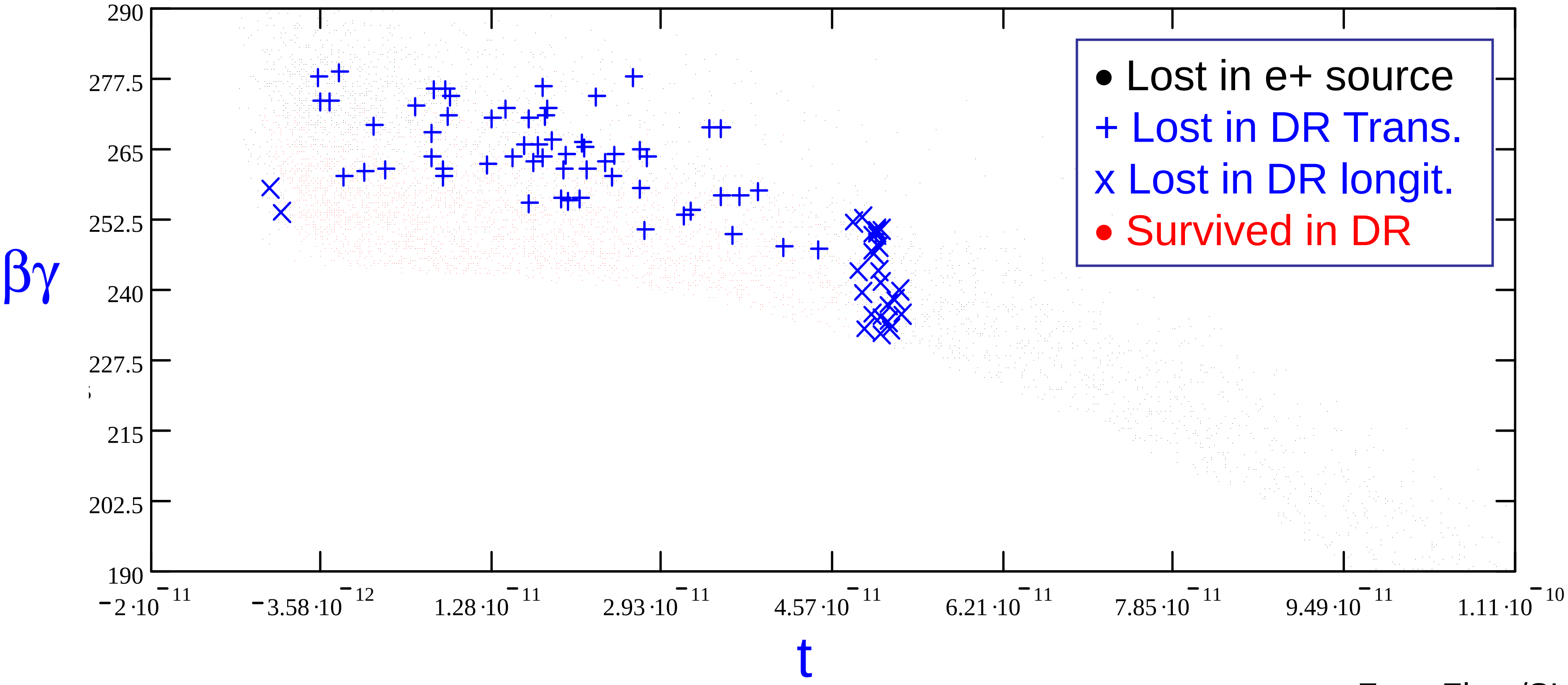
Collimators in Target hall transport

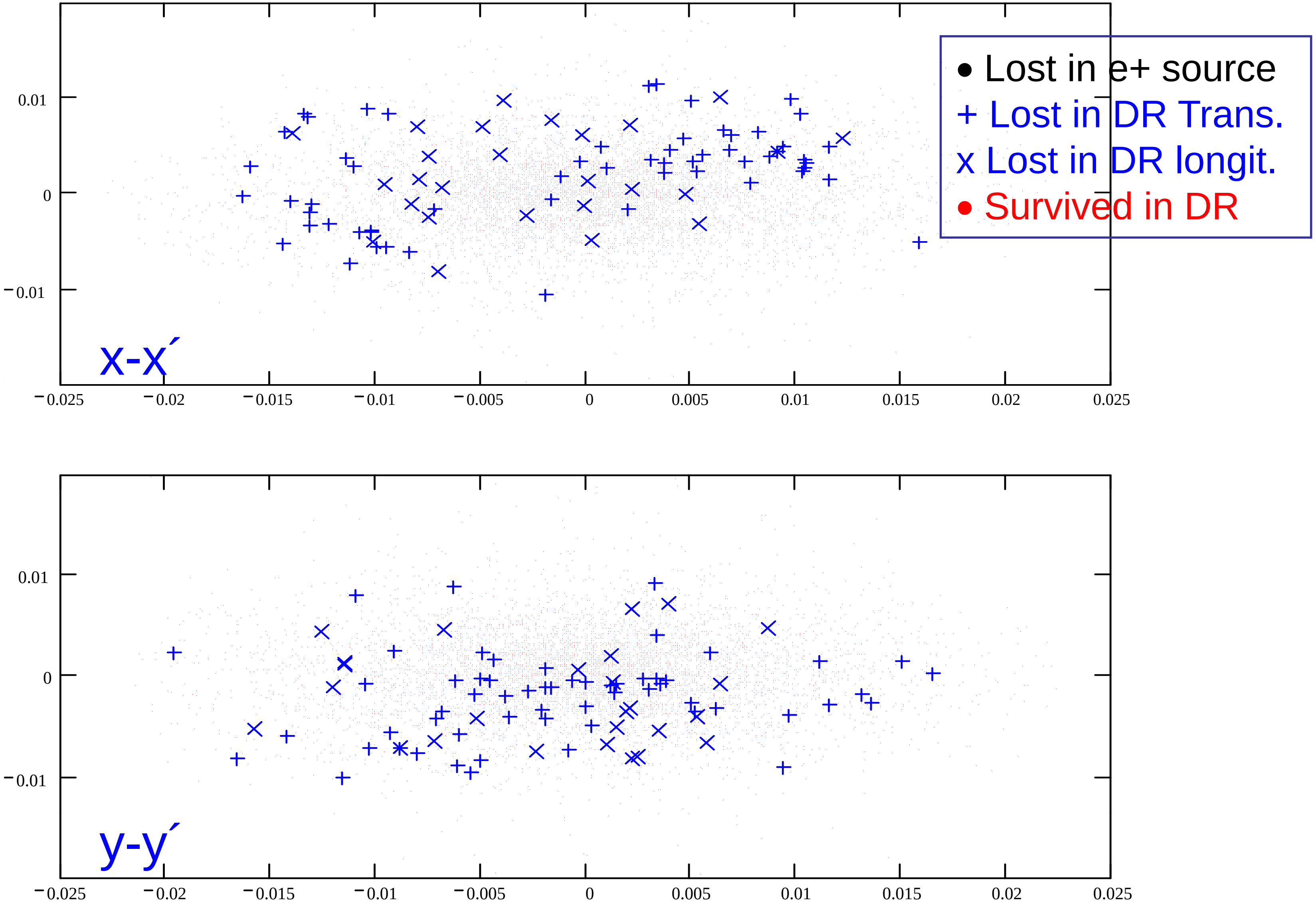
- 1st 4 collimators for β collimation; next 4 for initial energy collimation; next 3 to protect the magnets.
- To collimate e+ beyond DR transverse acceptance, two ways:
  - One straight way is to add β collimators at 5-GeV LTR before the DR but the power loss at 5-GeV is large.
  - The other way is to optimize collimators at low energy to collimate these particles.
- To collimate e+ beyond DR longitudinal acceptance at the low energy as much as possible; but definitely can't clean up at the low energy.

Collimation technique (1)

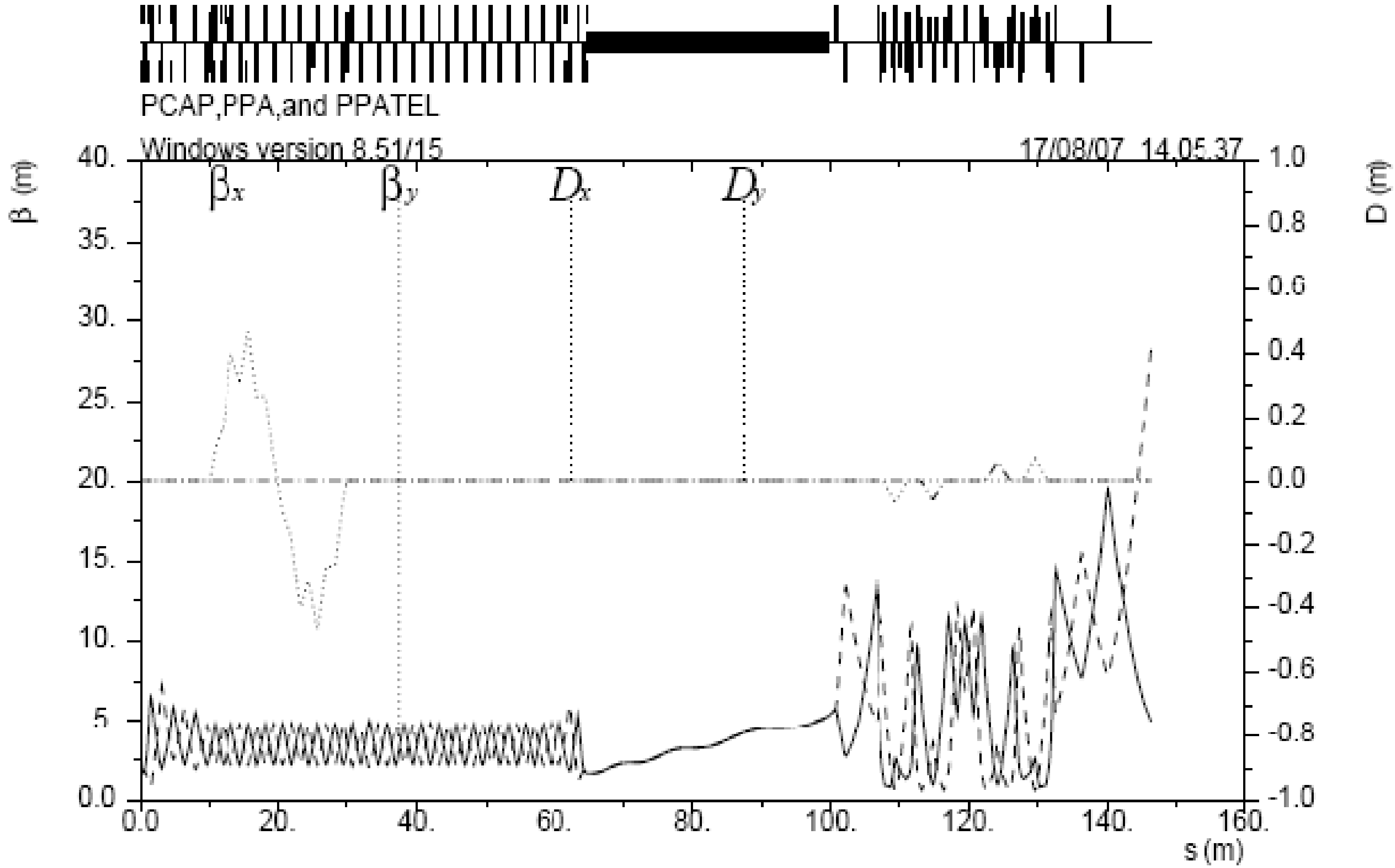
- Reconstruction of phase space from the end to the PCAP and identify the e+, which is beyond DR acceptance.
- To collimate these bad e+ as much as possible at the low energy region using energy and β collimators.



Collimation technique (con't)

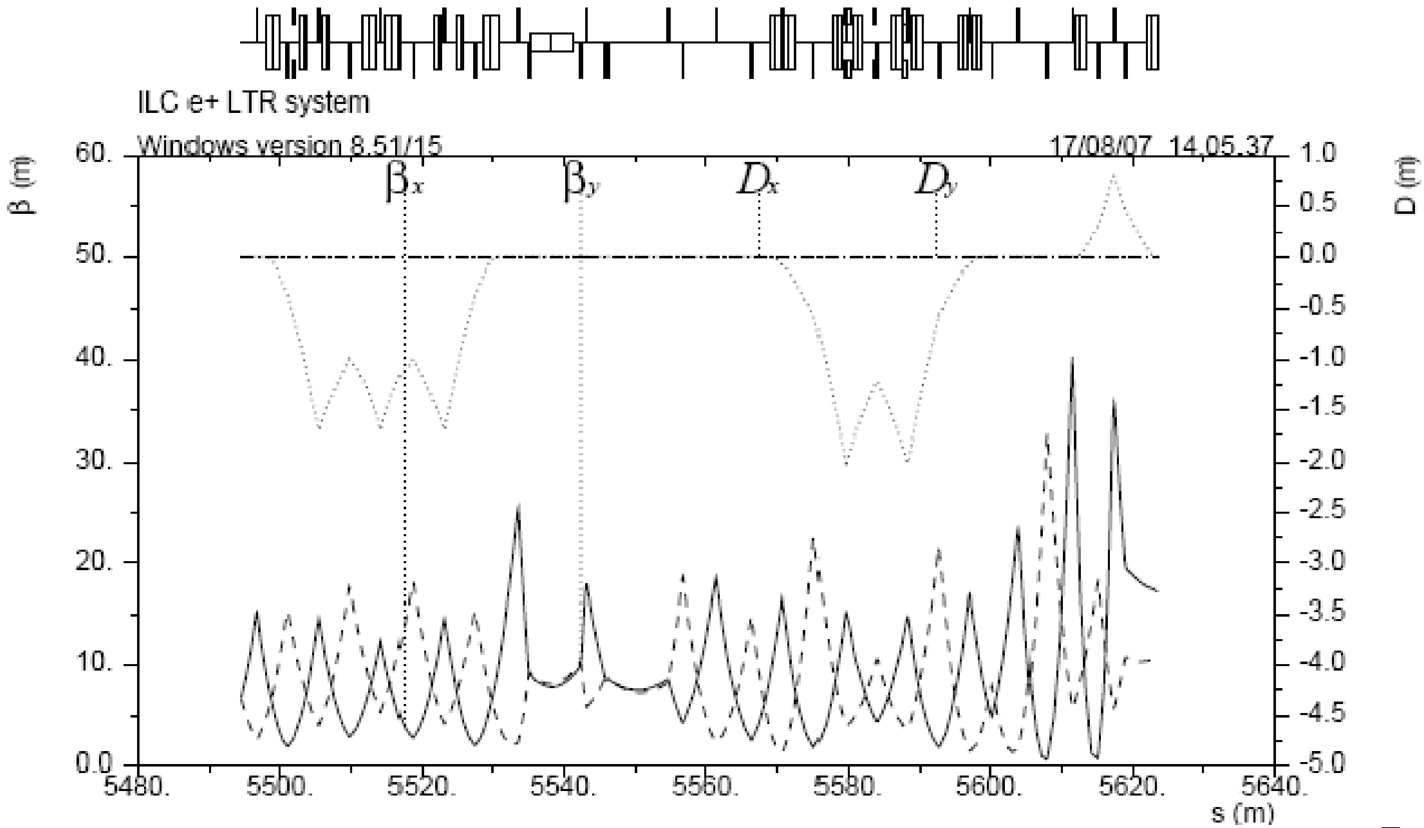


Collimators at target hall



Collimation at LTR

- 5 energy collimators are used to collimate e+ beyond DR longitudinal acceptance.
- All collimators including β and energy collimators at low energy and energy collimators at 5 GeV are optimized for the case of a shielded target and QWT.



Optimized collimators

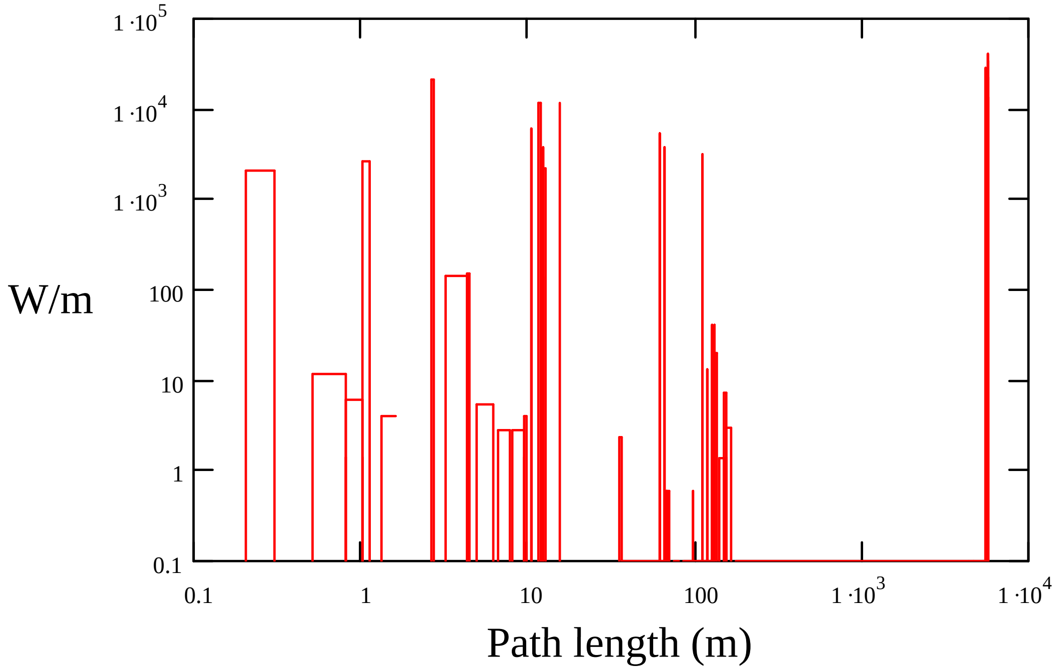
Collimator	Half aperture in x/y (mm)	Length (cm)	Entrance location s (m)
In PCAP:			
C1	15/15	10	0.2
C2	28/25	10	1.0
C3	22/22.5	10	2.6
C4	38/25	10	4.27
C5	23/75	10	10.321
C6	25/75	10	11.570
C7	30/60	10	12.320
C8	42/18	10	15.319
C9	23/30	10	61.672
C10	16/16	10	64.792
In PPATEL:			
C11	15/7.5	8	109.292
In LTR:			
C12	23/35	20	5501.887
C13	30/35	30	5579.153
C14	20/35	60	5579.756
C15	7.4/35	50	5583.350
C16	10.5/35	60	5587.643

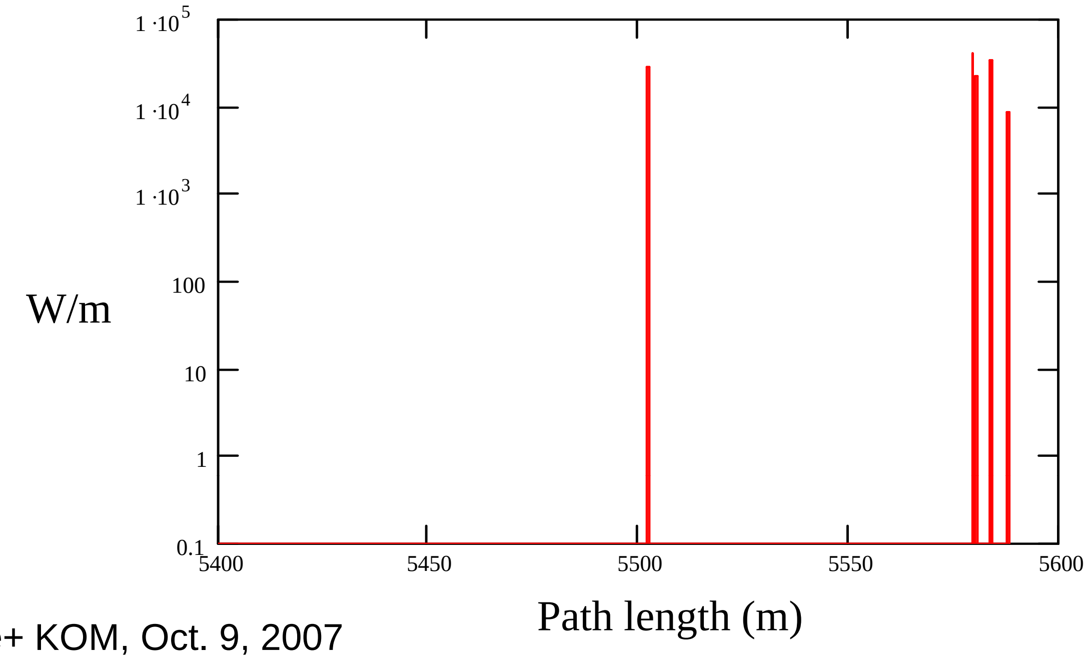
Physical apertures along the beamline

Components	Half aperture in x/y (cm)
Capture cavities	2.3/2.3
PCAP	7.5/7.5
PPA	2.3/2.3
PPATEL	7.5/7.5
PTRAN	7.5/7.5
PBSTR	3.7/3.7
LTR	
RF section	3.7/3.7
Solenoid	2.0/2.0
Others	7.5/3.5

Elegant-code tracking setup

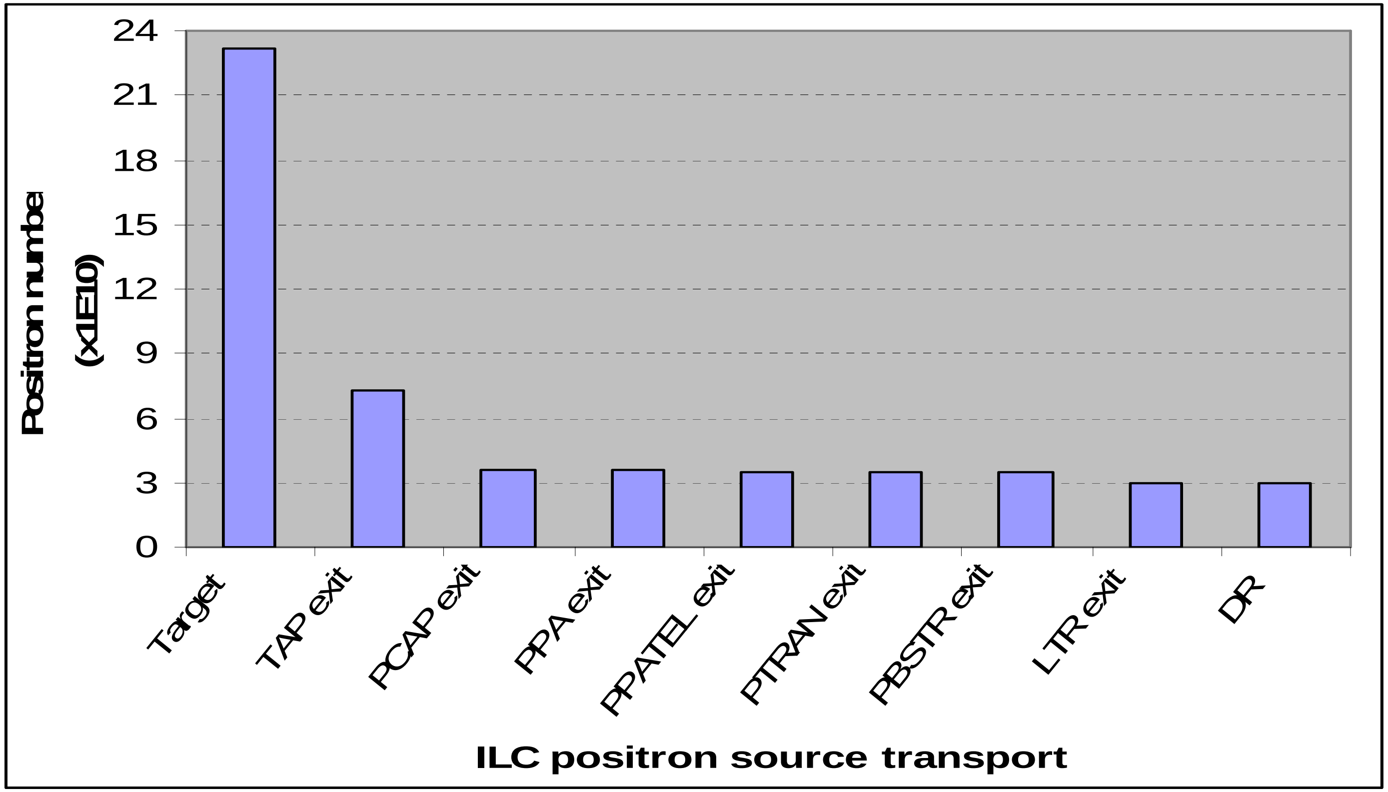
- Tracking from target to 125 MeV capture section is done by W. Liu; Elegant code is used to track the primary beam through the rest of the beamline.
- Tracking setup:
  - To apply energy dependence to all orders (except 2nd order for solenoid) in the beginning of the beamline including PCAP, PPA, and PPATEL.
  - To apply 2nd order matrix for the rest of the beamline, where the energy spread is reduced.
- Energy compression is optimized in the LTR to accommodate more e+ within the DR acceptance.
- To ensure 3E10 e+ captured in the DR.



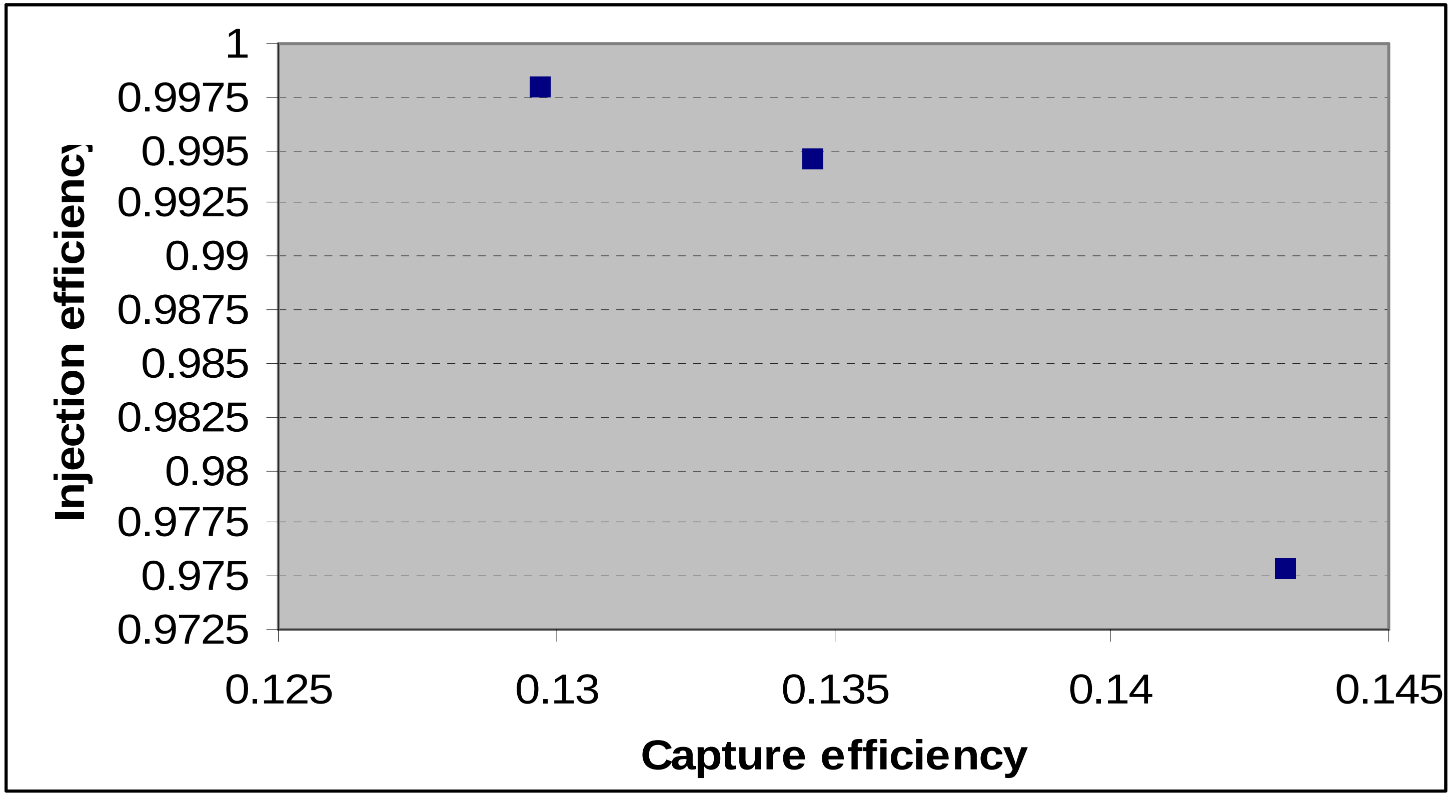


- Optimized for a shielded target and QWT.
- Assume 3E10 e+ captured in DR.
- Power loss in 5-GeV LTR collimators: 5.5 kW, 10.7 kW, 13 kW, 15.6 kW, and 5 kW.
- Power loss in DR is 640 W.
- Capture efficiency 13%, and injection efficiency 99.8%.

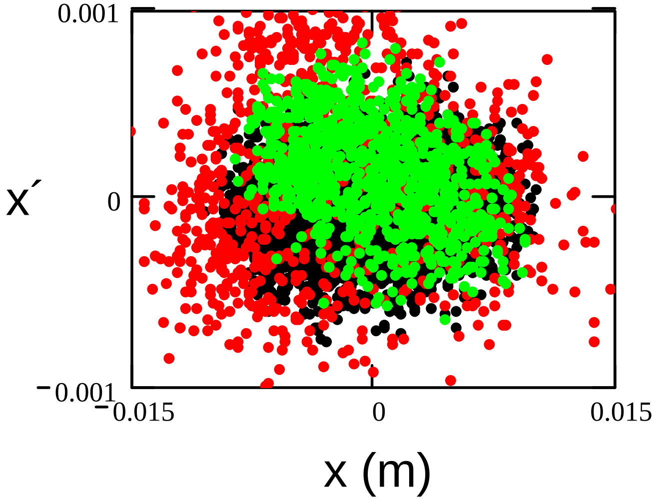
E+ number for power loss calculation

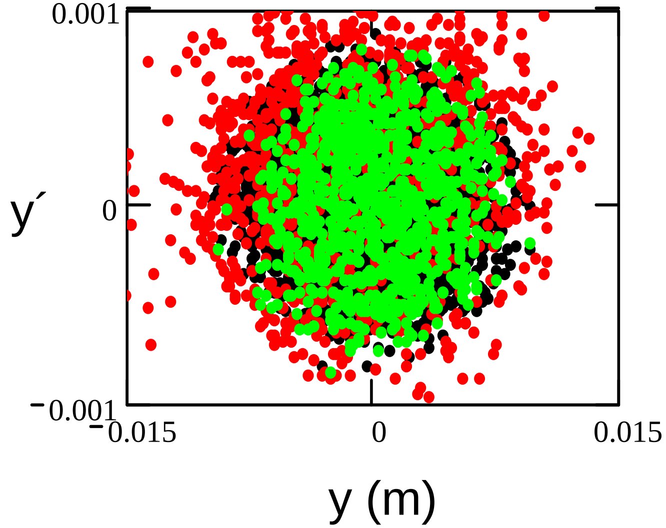


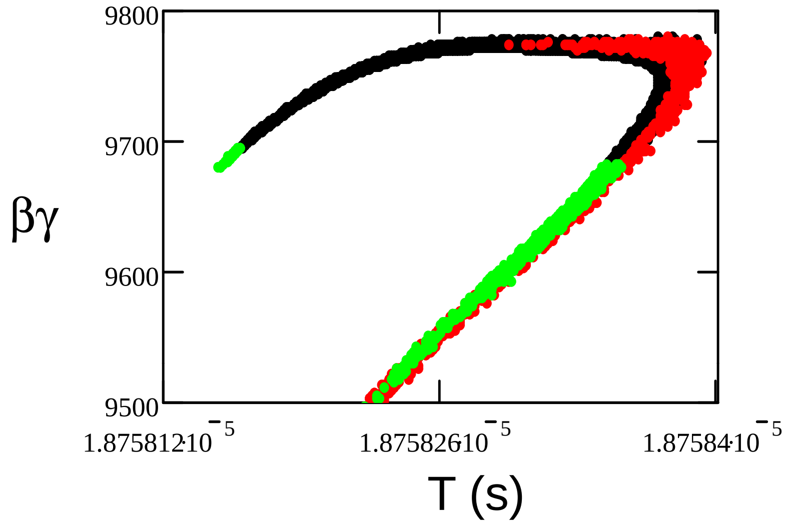
Injection efficiency vs capture efficiency



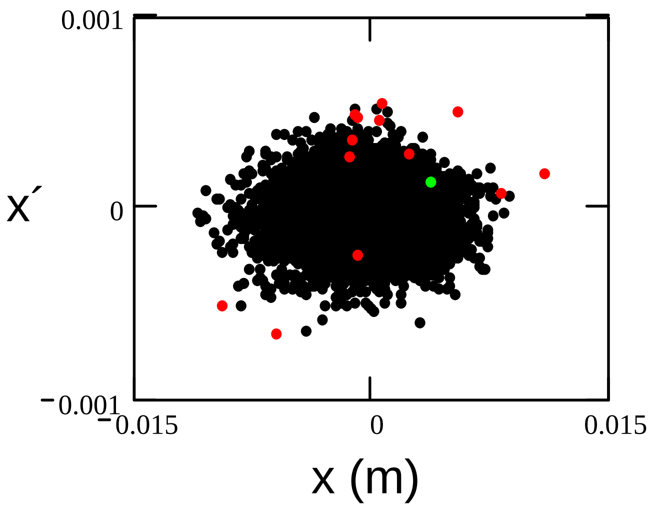
W/o the collimation

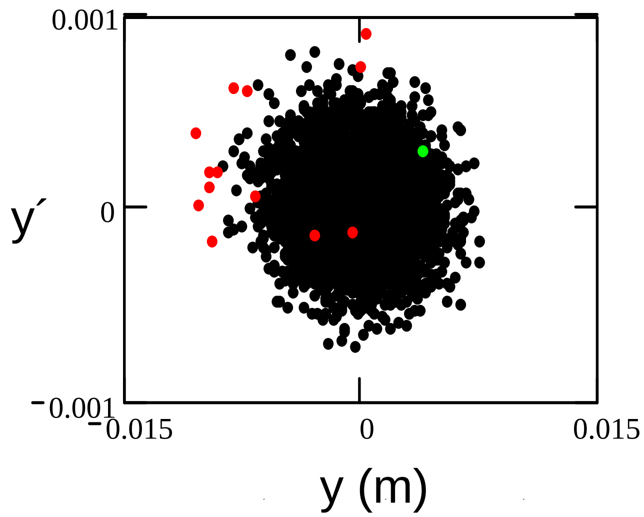


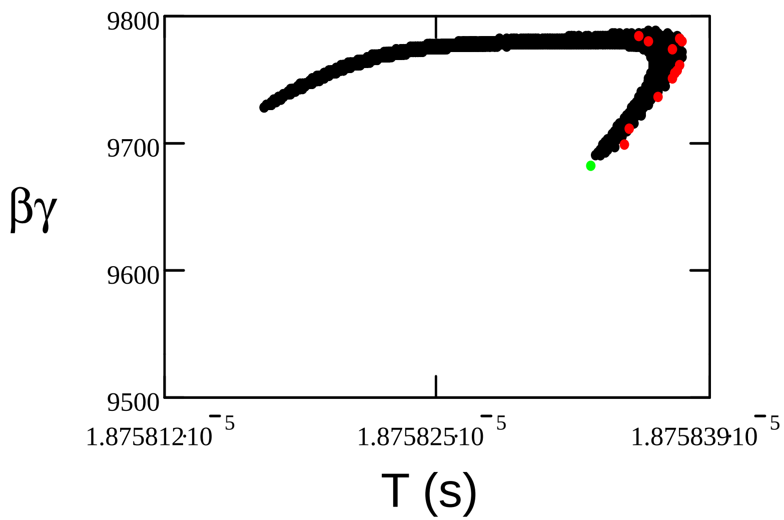




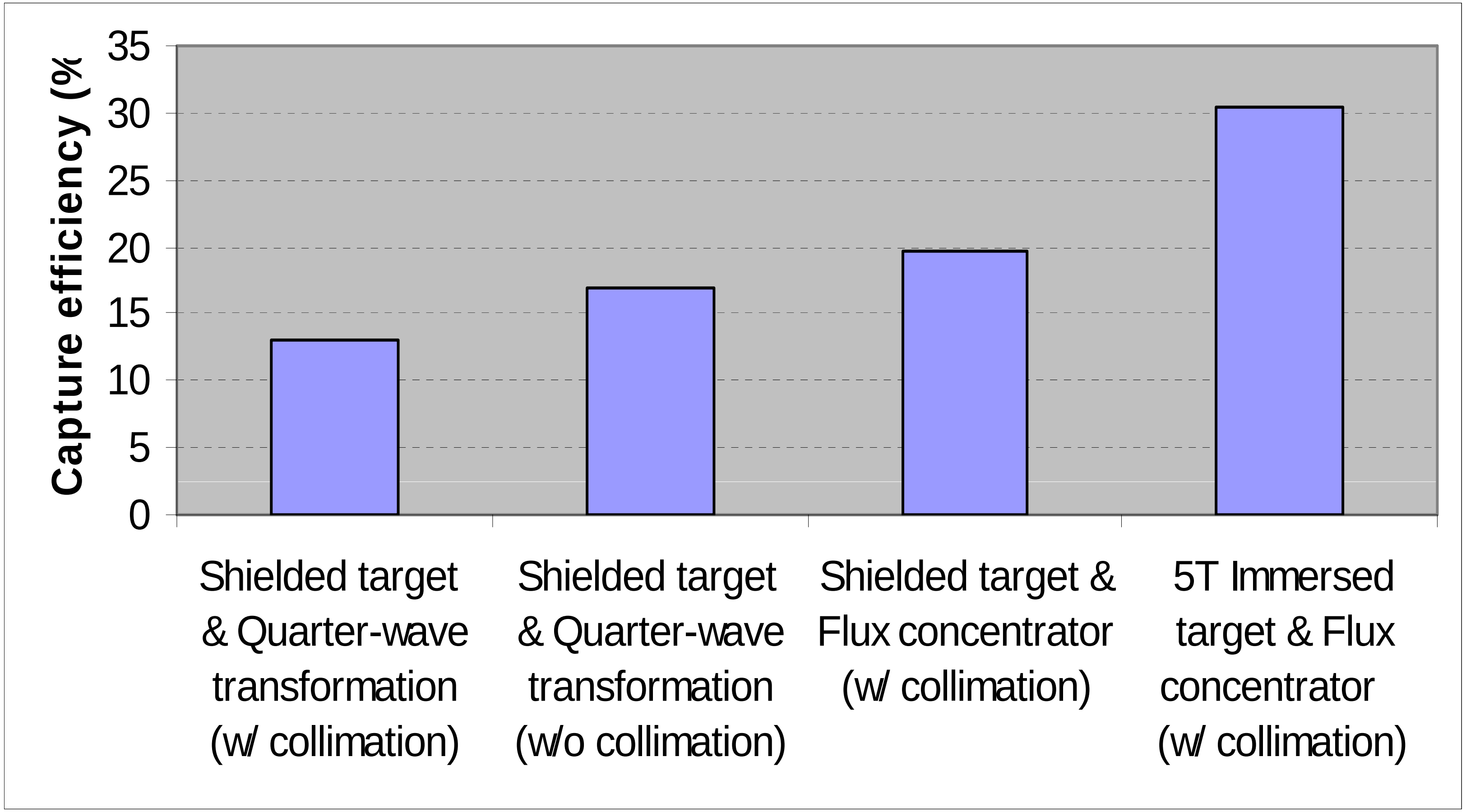
W/ the optimized collimation







Capture efficiency



Summary

- Full optics for e+ source ready:
  - Achieved:
    - 150 GeV e- insert chicane ready
    - e+ transport from capture section 125 MeV to the DR injection ready
  - Need to do
    - Need modify e- insert chicane to allow 1TeV upgrade
    - PCAP and PPATEL may accordingly change with e- chicane changes.
    - Expect some changes to integrate with engineering design.
    - Tolerances definition for beamline elements; tuning requirements, etc.
- Primary-beam collimation system is ready for the case of a shielded target with QWT:
  - Achieved:
    - Power loss in the beamline below the acceptable level.
    - Capture efficiency is 13% and injection efficiency is 99.8%.
    - Power loss in LTR collimators: 5.5 kW, 10.7 kW, 13 kW, 15.6 kW, and 5 kW.
    - Power loss in the DR is 640 W (given 3E10 e+ captured in DR).
    - 20% capture efficiency for a shielded target with FC
    - 30% capture efficiency for an immersed target with FC
  - Need to do:
    - The collimation apertures may have to be adjusted for the case of other than a shielded target with QWT to reduce power loss in DR
    - Further tracking including primary+secondary particles needed; Drozhdin of FNAL is doing the job.

Summary (con't)

- Status of optics resources:
  - SLAC developed full e+ source system optics and collimation in the past 2 years.
  - SLAC is no longer available for the work during EDR; have to transfer the optics to other people.
- ILC e+ source optics, collimation and tracking details refer to:
  - SLAC-PUB-12239, January 2007
  - SLAC-PUB-12798, September 2007